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PARTS I AND II

REGULATION OF THE COAL INDUSTRY— HEALTH AND SAFETY, SURFACE MINING AND OTHER ISSUES

A Report to the National Science Foundation

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Efforts to appraise impacts of the Coal Mine Health and Safety Act (CMHSA) of 1949 and surface mining regulations are reviewed. Also, an overview of numerous policies restricting the production and use of coal is presented. The effects of CMHSA on output were appraised by three methods, all of which indicate that CMHSA has reduced productivity significantly and concurrently raised coal mining costs 20 to 30 percent. Regression analyses demonstrate that costs appear to be five to twenty times higher than safety benefits. Data on potential health benefits suggest that they are unlikely to be great enough to raise benefits to equal costs. Hence, CMHSA advocates must show that benefit estimates are seriously understated. Analysis of surface mining regulations demonstrates that unless estimates of aesthetic benefits are grossly underestimated, surface mining reclamation entails costs which far exceed benefits. Global implications of these studies are not easily determined. A simulation study discusses health and safety regulations. A case study of a western strip mine provides extensive data which may or may not be representative. Overall, the conclusion is that the cost effectiveness of surface mining regulations is questionable.

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REGULATION OF THE COAL INDUSTRY-- HEALTH AND SAFETY, SURFACE MINE RECLAMATION AND OTHER POLICIES

Executive Summary

The present report primarily reviews efforts to appraise the impacts of the Coal Mine Health and Safety Act of 1969 (CMHSA) and surface mining regulation. However, an overview is provided of the numerous policies restricting the production and use of coal.

The effects of CMHSA on output were appraised in three fashions. First, all available data on underground coal mining in five leading producing states (West Virginia, Pennsylvania, Illinois, Ohio and Kentucky) were subjected to extensive regression analyses. Second, the impacts of the Act were simulated using a computer model of mine operations. Third, limited data were obtained from coal producers. Each approach produced the same conclusion--CMHSA has significantly reduced productivity and raised costs of coal mining by 20-30 percent.

This result is neither surprising nor undesirable per se. The premise behind CMHSA is that the institutions of the coal industry allowed excessive risks to worker health and safety. The critical question is whether the costs imposed by the Act produce benefits of sufficient value. This issue can only be partially appraised. The Act's contribution, if any, to improved worker health will not emerge for many years and even then may prove difficult to measure. What can be detected is the impact on safety and another element of our study was the regression analyses of the impact of the Act on accident rates. The analysis tends to confirm the expectation that the Act would produce lower accident rates.

The regression analyses of effects on productivity and injury rates were combined with other data to produce tentative estimates of the benefits and costs of CMHSA. The conclusion was that costs appear to be five to twenty times higher than safety benefits.

The higher ratio, moreover, prevails if we use the mean estimates of costs and benefits. To reduce the disparity to five to one, one has to assume costs lie at the low end of the plausible range of the estimate and the benefits at the high end (in both cases defined by 95 percent confidence interval band). The mean estimate for costs is $1.8 billion discounted at a five percent rate of interest. The costs include estimated increases in labor and capital costs and in the cost of mine inspection but exclude other operating cost increases. The mean value at a five percent interest rate of reduced injuries is $83 million. (Lost wages and reduced medical expenses are used as the measure of these benefits.) As noted, the mean costs are about 20 times the benefits. If we compare the lower limit to costs ($1.1 billion) to the upper limit to benefits ($215 million), we get a 0.2 benefit cost ratio. Such data as exist on potential health benefits suggest that they are unlikely to be large enough to raise benefits to equal costs.

Since the cost estimates probably are conservative, those who feel that the CMHSA has been desirable on balance must show that the benefit estimates are seriously understated.

The analysis of surface mining regulation was, by design, much more limited. A benefit cost analysis was conducted of a single mine in Montana. The study attempted to apply to the mine techniques previously used only for Appalachian surface mining. In addition, data were obtained on aesthetic values associated with restoration of the land. The results indicated that at a five percent rate of interest, nonaesthetic benefits were $300,000-$400,000 (depending upon whether the best use of land was for farming or ranching) and aesthetic benefits were $900,000. Costs were $18 million. Thus, the ratio of tangible benefits to costs is 0.02; the ratio when aesthetics are included only rises to 0.07. Thus, unless the estimates of aesthetics are grossly understated, surface mining reclamation produces costs far in excess of benefits.

The global implications of these conclusions are not easily determined. The benefit cost analysis of CMHSA relates to the present value of costs in five states over the first six years of the Act. The annualized cost at five percent interest would be at least $200 million. The simulation analysis as interpreted here suggests the actual costs may be several times higher.

If the case mine were typical of all surface mines in the U.S., the present value of the excess of costs over benefits during the next 40 years would be $27 billion. If these costs are prorated over the entire period until natural forces restore the land, annual excess costs of about $91 million would be incurred. Whether this is an attractive proportion is not immediately obvious. The analysis, if correct, suggests that the gross relative disparity between the assured benefits and costs translates into a small absolute annual excess cost. Enthusiasts for reclamation could claim the cost is easily justified by inadequately measured benefits. More critically, great perils exist in extrapolating the results for one mine to the whole country. Just how unrepresentative the Big Sky Mine may be is not readily apparent.

In any case, the analyses have failed to prove that the benefits of CMHSA or surface mine reclamation equal the costs. These results seem to be consistent with work in similar areas. As with this other work, two interpretations can be proposed. The first is that regulation really has been overdone. The second view is that the results are biased because available methods systematically understate benefits. We hope that our efforts to err toward generous estimates of benefits has lessened the problems of accurate evaluation. Thus, we would argue that we have at least demonstrated that considerable question exists about the cost effectiveness of these regulations.

Acknowledgements by the Principal Investigator

This study is the combination of several independent efforts. Three major separate efforts were undertaken--a simulation analysis of the effects of the Coal Mine Health and Safety Act on productivity, a statistical analysis of the effect of the Act on productivity and injury rates and a case study of a western surface mine.

I was assisted by an excellent team of associates to whom most of the credit is due. Professor Manula directed the simulation study with Charles Fettig and James Gresham assisting him. Fuller reports of this work appear in theses by Fettig and Gresham. I prepared the summary and extension of their work that appears as Chapter III of Part I of this report.

The statistical analysis of the Act involved work by Louise and Edward Julian and Gresham and Fettig. All four worked on the compilation of the data and Edward Julian prepared an initial study of productivity data for Illinois. However, it was Louise Julian who assumed the responsibility for completing the work and for preparing the final report. Edward Julian did all the work on the surface mine problem.

The debts accumulated along the way were considerable. We cannot thank explicitly the coal companies that aided us except to note that Peabody made available the data on Big Sky. The National Science Foundation was extremely supportive throughout and the patience of my project officer, Dr. Laurence Rosenberg, was particularly appreciated.

Reports of this magnitude place considerable strain on secretarial resources and the problems here were particularly acute. Thus, a special

appreciation is extended to those involved--my own secretary, Mrs. Theonas Fleming, my former secretary, Mrs. Janice Bellis, who both started the work and returned to assume a substantial part of the final typing, Mrs. Susan Farr and Mrs. Betty Stoltz who also assisted, and Mrs. Charlotte Joyner, the chief secretary of the Mineral Economics Department, who supervised the process of assigning all this work.

Introduction: Coal Regulation and National Energy Problems

While concerns over the environmental and health and safety impacts of coal production and use have existed for several centuries, the late 1960s marked the rise of greatly increased attention to these and other environmental and health and safety problems. At the time the increased interests arose, those expressing them suggested that the cures would be quick and inexpensive. The individual measures were alleged to have small monetary impacts, and in any case, a shift to greater imports of then very cheap foreign oil could offset many of the cost problems.

Experience has been far different from the predictions. At least four basic problems have been at work. First, the advocates of control failed to point out that knowledge of all the problems was incomplete and did not indicate that an increasingly more complex program would be necessary as more difficulties were identified. Second, the costing was done before sufficient experience had occurred to insure that accurate forecasts were possible. Costs often proved much higher than predicted. Third, cheap foreign oil disappeared in a series of price increases starting in 1971 and becoming particularly substantial in the wake of the turmoil following the 1973 Yom Kippur war. Fourth, a desire to limit the profits of fuel producers and electric utilities has hindered the ability of these firms to respond to altered conditions in energy.

The present report is primarily an effort to deal with two aspects of this expanded regulation of the coal industry. In particular, the impacts of the Coal Mine Health and Safety Act of 1969 are analyzed in considerable detail. Then, a more modest effort is made, by use of a case study, to discuss the problems of benefit cost analysis relating to reclamation of surface mines in the Northern Great Plains.

The report is divided into three parts. This first part consists, in addition to the present section, an effort to provide perspective on coal regulations appears as subsection II. Then a final section consists of a jointly written paper summarizing one aspect of our study of health and safety regulation--a simulation study done in collaboration with Professor Charles B. Manula of the Department of Mineral Engineering. The second and third parts of the full report are each autonomous independent studies. Part II consists of a statistical analysis of the effects of the Coal Mine Health and Safety Act on output per man day and injury rates in five leading coal producing states--West Virginia, Pennsylvania, Illinois, Ohio, and Kentucky. Kentucky is divided between its eastern and western portion and each portion is analyzed separately. This work was done under my supervision by Louise Julian. Then part three is the case study of a western strip mine; this work was done by Edward Julian.

As background to this review, this introduction makes further comments about the four problems of energy policy outlined above. We may examine first the growth of such policies. Policymakers have both identified more problems and found that the problems that had been identified were more complex than originally believed. Thus, a potentially significant change in the scope of air pollution regulation has been concern over the composition as well as the magnitude of particle emissions. To the general problems from all types of particulates has been added fears that some, known collectively as trace elements, have particular toxic effects. The identification of particularly toxic substances requiring special controls also has become an element in water pollution and solid waste disposal policies. As discussed in the next section, the strategies for controlling a given pollutant have become more complex as a result of decisions to vary the regulations with certain regional problems. As would be expected, the stringency of regulations generally must be greater when pollution is greater. Another development has been the insistance that when an area is exceptionally free from pollution, extra efforts should be made to preserve this superior quality.

Undoubtedly the easiest to document example of the problems of accurate appraisal of the economics of pollution control is that of stack gas scrubbers to limit the emissions of sulfur dioxides from fossil fuel burning plants. In the late 1960s, it was alleged that the requisite technology was available at costs of perhaps five cents per million Btu in then current dollars and thus equivalent to about 10 cents in 1978 dollars. A decade later the reliability of the technology still remains unclear and the cost estimates tend to be much higher--well over 50 cents per million Btu according to estimates made for the U. S. Environmental Protection Agency.[1]

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[1] See ICF Inc., Still Further Analyses of Alternative New Source Performance Standards for New Coal-Fired Powerplants, Appendix B, Washington: 1979. The appendix contains estimates of capital costs in dollars per kilowatt of capacity and operating costs in mills per kilowatt hour generated. For a case in which full scrubbing is required for all plants, the capital costs range from $107 per kilowatt for low (less than 0.4 pounds per million Btu) sulfur coal to $118 for high (3.3 pounds or more of sulfur)sulfur coal. At a 7 percent capacity factor and an annual capital charge of 16 percent, the $107 capital costs would have carrying costs of about 2.6 mills per kilowatt hour. Raising capital costs to $118, employing an 18 percent annual charge rate, and setting the capacity factor at 60 percent raises the cost to 4.2 mills. Total direct costs are then 4.5 mills in the lower cost case and 6.8 mills in the higher cost case. Since a million Btu produces about 100 kilowatt hours, the respective costs per million Btu are 45 to 68 cents. To this can be added a fuel cost penalty of 4.35 percent; since no utilities in the U.S. pay less than 40 cents per million Btu for coal, the fuel penalty is at least another two cents. Finally, the plant must be derated by about 2.75 percent; at a plant cost of $400 a kilowatt, this adds another three cents to the costs.

Probably, the most pervasive unexpected result of regulation has been the delays to decision-making created by the mechanics of the processes. Rule-making has been extremely time-consuming. The wide variety of permits required to operate a facility generally must be supported by expensive studies proving that adequate compliance with regulations will be insured. Considerable time may be consumed in preparing the required material, the approval process may be long, and at this, as with earlier and later stages of the regulatory process, legal challenges may be made of the regulatory decisions.

The disappearance of cheap oil prices is another highly controversial aspect of energy developments. Observers disagree about whether the rises reflect a sudden realization on the part of foreign oil producers that their resources were rapidly approaching exhaustion or just the ability to create a monopoly of the oil market. Professor M. A. Adelman has provided calculations that given the costs of alternative fuel and the cost of capital it is not profitable for members of the Organization of Oil Exporting Countries (OPEC) to withhold output for more profitable future sales. Most discussions of the issue tend to sidestep this criticism. Such a well publicized effort as that of the Workshop on Alternative Energy Strategies tended to sidestep Adelman's argument; it is not clear whether the greater supply problems that the Workshop predicted arises from an oil depletion problem, an imagined technological limit on the ability to develop the capacity, or a deliberate desire to limit output to promote monopoly. However, Ali D. Johany has argued that since Adelman underestimates future energy costs and overestimates interest rates, the Adelman argument grossly understates the attractiveness of withholding oil. Johany also has an explanation for the timing of the rise; he asserts that the OPEC countries had attained the power that they formerly lacked to make their own decisions about the optimal rate of production.[2] Johany's argument rested on tenuous assumptions when he presented his work. The 1979 oil price rises make his argument seem quite dubious since according to his theory the rises should have been much smaller.

Should Adelman be correct that the problem is monopoly rather than exhaustion, questions then arise about what caused the monopoly and whether the forces are reversible. Adelman here too has controversial views. He contends that the only power the OPEC countries possess is their ability to frighten the consuming nations by a threat of cutoff of oil supplies. He further argued that initially at least the OPEC countries would not have been willing to stick to a decision to withhold oil. However, once established the cartelization is difficult to dislodge at least unless one or more consuming country governments are willing to create a climate in which OPEC countries, like members of past cartels, are encouraged to undercut each other. Other observers have argued that OPEC cannot be undermined either because it is an unusually cohesive group or because the only members with significant ability to expand capacity constitute a sufficiently small subgroup with similar ends that they can profitably control prices in the interests of the entire group. In the limit, this last argument reduces to a contention that Saudi Arabia is the only country with spare capacity and it sets prices in its own interest. (It is worth noting the main defect of this line of reasoning. The existence of countries with absolutely no spare capacity and countries with ample capacity expansion potential would create the maximum possible conflict. The countries with zero spare capacity would like to see prices at the highest possible level consistent with selling their capacity--i.e., the price at which it is impossible for anyone else to sell anything.)

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[2] Johany's work is reported in Walter J. Mead "Political-Economic Problems of Energy--A Synthesis", Natural Resources Journal, 18 (October 1978), 707.

More attention should be given the policy decisions to restrain the profitability of U.S. domestic energy producers. The basic source of the problem is easily identified; substantial so-called windfall profits would accrue to the owners of mineral deposits with extraction costs below the price of OPEC oil. Fears existed of undue enrichment of these companies, particularly the major oil producers who as operators of oil fields in OPEC countries were held responsible for the price rises. (Whether the culpability was real or resulted from the desire to retaliate against the most convenient target is still another controversial argument.)

The most obvious aspects of this tendency has been the continuation of price control on natural gas and their introduction for crude oil and products. It has been suggested that the controls were an effort to subdivide producers into categories that roughly reflected the differences in the ability to expand output. Higher ceilings were given classes of oil and gas fields that seem more likely to be able to expand output. Whether the complex system produced benefits commensurate with the costs has been bitterly debated.

A less publicized aspect of the reaction to fears of windfall profits has involved extensive modification of the systems by which the federal government leases energy resources and levies charges for the rights to these leases. The most extreme response was the moratorium on coal leasing instituted in 1971 and as of December 1979, still in progress. (See Section II). In addition, the rules under which oil, gas, and coal may be leased have been altered by Congress.

Still another aspect of the phenomenon is the widespread resistance of state regulatory agencies to authorization of either rate increases or capacity additions by electric utilities. Rate regulation remains the preserve of old-line public utility commissions, and most of these commissions seem to have been engaged in battles with utilities at least over rate relief. Disputes over expansion plans have involved, not only various public utility commissions, but also special siting agencies whose creation was supposed to streamline the permitting process.

In sum, then an ever increasing network of restrictions to decision-making in the energy realm has arisen since the middle 1960s. Reasonable arguments exist for the imposition of control at least in the environmental realm. Economic analysis provides convincing arguments about why pollution control cannot be effected without government intervention. However, considerable questions can be raised about the wisdom of intervention in other realms; it is not clear that the windfall profits and monopoly problems are serious enough to justify any action, let alone the presently prevailing policies. Moreover, acceptance of the principle that some environmental policies are needed certainly does not imply that the prevailing policies are ideal. The desire here is not to settle all these arguments, but to create an appreciation of their existence and to focus on what can be said about the policy areas that are our special concern.

While we claim only to have developed tentative estimates of impacts, we think our results are a useful first step. We conclude that the best way to resolve the issues more conclusively would be for the coal industry to cooperate more fully with a study of the issues, particularly of health and safety. We suspect that the best way to proceed on the health and safety issue would be to entrust the research coordination to a group of impartial analysts unassociated with the coal industry, the U.S. government, or any group with strong advocacy positions in the coal realm and funded from a comparably disinterested source such as a federal government agency without a particular position or by a private foundation.

The view of surface mining was more limited. We dealt with a single question--what were the prospects of adapting existing techniques of applied benefit cost analysis to western surface mining. The enormous literature on benefit cost analysis included efforts to assess the benefits and costs of control of surface mining in Appalachia. The literature on coal problems continually states that the West is radically different from Appalachia, but no evidence has been given about what difference this may make. Our intent was to deal with this hiatus by conducting a benefit cost analysis of a specific mine. Our ability to do so was greatly facilitated because Montana law requires the disclosure of considerable amounts of data on surface mining operations in the state. Thus, a leading producer in the state could make available data on its operations without disclosing any confidential material.

II. The Coal Alternative

A persistent theme in discussions of coal industry prospects is the blatant disparity between the enthusiastic statements by various politicians about the important role that coal should play in U.S. energy supply and the tendency of these politicians to create severe barriers to the production and use of coal. It is only a slight understatement to argue that the only practical thrust of public policy has been to discourage the alleged needed growth in coal use. The only real compensation that has occurred has been that similar impediments have been imposed on other energy sources. The coal industry might have been harmed less than other sectors.

It is impossible to resolve totally the debate over proper energy policy. Good rationales exist for government action in many, but not all, the areas in which intervention has occurred. Therefore, it is conceivable that what is undesirable is the expansion of coal use and that what should be criticized is calls for greater coal use. I am prepared to concede that certain aspects of the call to greater coal use--particularly in the realm of synthetic fuels--are based on an inadequate perception of the problems of coal use and excessive fears about the prospects for oil and gas supplies from conventional sources. However, it has become increasingly apparent that this aspect of the issue is of secondary concern. No evidence exists that industry is making serious commitments on the basis of overoptimism about coal. The paramount current problem is that decision-making throughout the energy sector is being paralyzed by a mass of regulations and it is highly probable that in coal, as in other areas, this paralysis will create severe difficulties for the U.S. economy. Whether the present governmental enthusiasm for synthetic fuels from coal will prove less transitory than similar prior suggestions remains unclear.

Even here, I have to qualify the argument somewhat. It is possible that the impacts of this policy stance will be limited to causing greater imports of oil than would have otherwise have occurred and that the increased direct cost of energy produced by this import increase can be rationalized by the indirect benefits of a better environment. For at least two reasons, I have severe reservations about this line of reasoning. If one considers how and where coal (and nuclear power) is consumed, it becomes apparent that shifting to oil would be by no means a simple task. Coal is principally an electric utility fuel, and the consuming electric utility plants are predominantly located inland. The logistics of getting the required amounts of oil to such plants would be formidable. Second, many of the barriers arise from fear of energy monopoly, and any impediments to energy development that arise from fear of what I would argue to be the nonproblem of monopoly would be costs without visible offsetting benefits.

The principal regulatory problems of the coal industry include:

1. the regulation of health and safety in coal mining
2. the regulation of surface mining damages to land
3. the efforts of state and federal governments to impose charges on coal exploitation and to control private access to coal resources
4. the general retarding of the decision making process created by the requirement for environmental impact statements
5. stringent air pollution regulations
6. the reluctance of state agencies to allow expansion of electric utilities.

Let me deal with the issues in reverse order thus starting with the least familiar. The literature on public utility regulation has tended to describe the regulators as acting rather passively and uncritically approving whatever the utilities desired. With hindsight, it appears that a critical consideration was that no pressing need existed to be aggressive. The traditional problems of lags between cost changes and price changes and of possible laxity about cost control were minor matters in an era of low and falling rates.

The new climate of rising costs has inspired substantially more vigorous action by regulators. In addition, environmental concerns have produced a new area of regulation. In some cases, public utility commissions have assumed responsibilities for action in the area, and in others, separate agencies have become involved.

Discord has arisen over both electric utility rates and about the specifics of expansion plans. In broad outline, the utilities are criticized for inadequate attention to cost control, proposing unrealistic expansion plans, or selecting the improper type and location of the plants. The utilities counter by claiming that the prevailing rates are not allowing an adequate return on investment and that the state agencies are imprudently risking power shortages.

One would generally expect that utilities would have a particularly great and possibly excessive concern over such capacity problems. Given guaranteed rates of return, the profit consequences of overbuilding are muted. Given the uproars produced by inadequate capacity, the consequences of inadequate capacity are quite unpleasant to the company.

It would appear that the situation is aggravated by a peculiarity in the way in which regulatory agencies insure adequate rates of return. Apparently, many of the formulas used to determine the carrying charges on plants under construction provide inadequate compensation, and this deficiency is made up by surcharges on rates to current consumers. Regulatory agencies validly have argued that since future users get the benefits of this capacity, current consumers should not have to pay for the costs. However, the logical next step of the argument--that a method should be devised to charge future customers adequately--has not been taken, at least to the degree many utilities consider desirable.

On the other side, the utility commissions and other regulatory agencies do appear to be more concerned with avoiding immediate problems and inadequately concerned with future developments. It is easier to find confessions of error of this sort than validation of concerns that utilities are grossly overestimating demands for the 1980s. We have had the particularly blatant example of the California siting commission that secured numerous reports alleging that conservation, alternative energy sources such as solar energy, and the construction of a coal-fired plant obviated the need to add the nuclear plant. Within a year of the killing of that nuclear plant, it was admitted that power shortages would be a danger, and pleas were issued to allow construction of an oil-fired plant.

In general, it would appear that regulators have shown inadequate appreciation of the basic problems involved. In particular, the problems of accurate prediction seem to be seriously neglected. It has long been recognized among forecasters that the easy to use techniques will only work when market conditions are stable and even then forecasts extending more than a decade into the future would have an extremely tenuous basis.

The delays associated with energy regulation imply that expansion decisions must be made a decade or more before the plant will start operating. We are thus seeking to make decisions about time periods that were always considered too distant to be appraised accurately. To make matters worse, market conditions have been highly unstable, and our forecasting abilities have drastically decreased just when we need better forecasts. (Substantial and impressive efforts have been made to respond to these needs by developing better models of the overall energy market and its key components. As valuable as this work has been, it cannot and did not succeed in overcoming the enormous problems inherent in forecasting.)

Air pollution regulation has been a primary influence on the level and geographic distribution of the production and consumption of coal in the United States. Review of these problems must consider the basic questions involved, the evolution of policy, and the resulting response. The pollution problem with by far the most significant influence on the coal industry has been sulfur oxide pollution. Sulfur oxides are only one of several pollutants associated with coal use, but the others have caused fewer difficulties. Nitrogen oxide controls have not been made stringent enough to cause problems; control technology for particulate emissions has long been well established. Severe limits on sulfur oxide emissions combined with difficulties in compliance have made sulfur oxides the principal problem.

A multifaceted program has emerged for sulfur oxide emission control. A fundamental distinction exists between programs designed to control what the regulatory jargon refers to as ambient air quality--the concentration of pollutants in the atmosphere and specific source rules--those applicable to an individual facility. Thus, understanding of air pollution regulations must encompass the details of both approaches and the relationship between them.

The fundamental norms for ambient air quality are standards set by various advisory panels assessing the available data on pollution damages.

Both primary standards designed to eliminate health effects and secondary standards designed to eliminate damages to property and other harms are established. As many observers point out, our knowledge of pollution effects is too imperfect for us to set these norms accurately. Moreover, the cutoff concept may be based on a convenient fiction. It is unlikely that a precise cutoff point below which no damages occur really exists, but since the laws require such cutoffs to be defined, criterions had to be set. Presumably a rough estimate is being made of the level of abatement at which marginal benefits equal marginal costs.

These standards set a ceiling on pollution levels, and any state or local government was free to set more stringent standards. To complicate matters further, a phrase in the 1970 Clean Air Amendments setting a goal of preserving and enhancing air quality was interpreted by the courts to imply that areas with air quality sufficiently better than that meeting national standards could not allow significant deterioration of that quality.

This decision produced severe implementation problems. Considerable question arose about what areas were covered and the allowable deterioration in such areas. Ultimately, new legislation, namely part of the Clean Air Amendments of 1977, was required to set criterions for determining what areas were covered by the rules and what the rules would be. The two key elements of the rules are definition of the areas covered and statement of the applicable rules. The regulations are stated in terms of the amount of allowable pollution increases. Covered areas can be assigned to one of three classes--I, II, and III in descending order of strictness. The law defines specific allowable levels of increases in ambient air concentrations of sulfur oxides and particulates for each class and requires studies to establish rules for other pollutants. The rules allow increases in pollution due to temporary influences such as construction and to a fuel conversion for which adequate pollution control equipment is not immediately available.

The main rule on classification is that all regions meeting ambient air standards are covered, initially classified as class II regions, but may be reclassified if the state and local governments agree. (Indian lands are put under the control of the tribes, but states can ask the administrator of the U.S. Environmental Protection Agency (EPA) to change the tribal decisions.) Additional complications are introduced in the treatment of preamendment class I areas and various categories of public land. All areas that were class I before the amendments to the Clean Air Act, international parks, national wilderness areas, and national memorial parks larger than 5,000 acres and national parks that are both larger than 6,000 acres and extant before the amendment must be class I regions. Other categories of public land such as new national parks and wildernesses and national monuments must be class I or class II areas if the area exceeds 10,000 acres.

The specific source approach was to mandate emission control practices for various classes of facilities. The first rules relevant to coal users were the 1971 new source performance standards for large stationary boilers. These standards among other things limited sulfur dioxide emissions from new coal fired plants to 1.2 pounds per million Btu. A new plant was one started after the rules were promulgated. For reasons I discuss later, the 1971 standards encouraged a desire to use western coal that was disturbing to various interest groups. The Clean Air Amendments of 1977, therefore, included the requirement that specific sources should use the best available control technology (BACT). Since the enactment of the Amendments, the Environmental Protection Agency (EPA) has been struggling to develop rules to apply this concept to control of sulfur dioxide emissions from coal burning. This has proved an extremely difficult task.

Basically, BACT shifts emphasis from the level of emissions to the level of emission control. Instead of a 1.2 pound standard, one might mandate say 80 or 90 percent sulfur removal. EPA has found that a literal interpretation of the concept has several drawbacks. It is agreed that it would defeat the objective of BACT to set a required cleaning rate that ignored the absolute level of emissions. A high cleaning rate on a particularly dirty coal could produce more pollution than the old 1.2 pound standard. Thus, it became clear that in addition to the basic rule about the rate of cleanup, provisions had to be included to set upper limits on the rate of emissions. A parallel question was raised about how to treat exceptionally low sulfur coal. It was suggested that it made little sense to subject such coal to the same degree of cleanup as higher sulfur coal. Thus, EPA has had to decide upon a basic cleanup goal, upper limits on emissions, and what lessening, if any, of the basic requirements would be allowed for lower sulfur coal. Considerable controversy exists over both the ceilings and the treatment of lower sulfur coals. As noted, the purpose of the ceiling is to prevent resort to high sulfur coals. Specifically, the ceiling effectively sets an upper limit to the sulfur content of coal burned. The more stringent the ceiling the fewer the coals that will meet it. Similarly, the easier treatment of lower sulfur coals broadens the ability to use them. Those who are interested in encouraging production of higher sulfur coal are fighting for more liberal ceilings; those who wish to encourage low sulfur coal use seek more liberal treatment of such coal. The impetus for higher ceilings has come from Midwestern coal producers who fear they will otherwise be regulated out of business. The push for more favorable treatment of low sulfur coal has been led by the Department of Energy which feels that such treatment would lessen the deleterious effect of BACT on coal use without seriously harming the environment. (See ICF Inc. 1978a, 1978b, and 1979, and my review of them in Gordon 1979).

The Clean Air Amendments introduce still another element--the local coal provision by which EPA could force use of local coal to prevent dislocation of local industry. This provision was pushed through by members of Congress from Appalachian states thinking they were protecting the region from competition from the West. To the unpleasant surprise of many of them, the first use of the provision was to ban the use in Ohio of coal produced elsewhere in Appalachia because Ohio coal would be displaced. The decision has produced predictable outcries. The Ohio utilities complain that they will incur enormous costs to benefit a few miners; coal producers elsewhere in Appalachia and their representatives feel betrayed; EPA reached a compromise by which pollution regulations were changed to allow burning higher sulfur coal without using scrubbers.

These regulatory battles are intimately connected with the realities of air pollution control technology (or possibly more accurately, the misperception of these realities by the decision makers).

Basically, three alternatives exist for reducing pollution from sulfur oxides--shifting to an inherently low sulfur fuel, using a fuel from which sulfur has been removed prior to combustion, or capturing the sulfur after combustion. Depending upon the prevailing requirement, it is possible to comply with regulations by employing naturally low sulfur coal, oil, or natural gas. To the best of our knowledge, the most ample supplies by far of low sulfur coal occur in the Great Plains--particularly in Montana and Wyoming. Lesser supplies are available in parts of Appalachia--notably southern West Virginia and eastern Kentucky.

A wide range of removal techniques exist. With gas, sulfur removal is routinely and easily performed by processes that were developed long before concern emerged over sulfur oxides. The technology was developed for the quite different purpose of making it practical to transport the gas by preventing the corrosion of pipelines that would have occurred if the sulfur had not been removed. The rise of air pollution concerns led to the rapid development of techniques for greatly reducing the sulfur content of oil products.

Comparable success has not prevailed in pretreatment of coal. Conventional cleaning methods do remove some of the sulfur, and it has been suggested that greater reliance on cleaning might make a significant contribution to sulfur reduction. It has also been proposed that alternative cleaning techniques including chemical ones might be adopted. Another route has been that of developing a variety of synthetic fuels and undertaking cleanup of these synthetics. The proposals include three basic areas--the synthesis of conventional oil and gas, the development of lower grade liquids or gases for boiler use, and the special case of solvent refining which produces a liquid that solidifies after cooling and could be used hot or cold.

Treatment during combustion could be effected by use of new combustion technologies such as a fluidized bed--which as the name suggests involves combusting coal mixed in a bed with other materials that is "fluidized" by a steam of air and combustion gases. Alternatively, cleanup devices known as stack gas scrubbers could be added to capture and clean up the gases prior to emission.

In practice, the only one of the pre- or post-combustion techniques that appears remotely feasible as of mid 1979 is stack gas scrubbing. Even here, the truth of the matter is at best obscure. EPA has been planning BACT implementation on the assumption that highly reliable scrubbers are available. However, EPA also has been employing a contractor called PEDco Environmental to monitor actual scrubber performance, and my reading of the results through 1978 of this PEDco work is that high reliability remains something yet to have been attained. The record of scrubbers used on heavily operated power plants using high sulfur coal has been quite unimpressive. Breakdowns are frequent even though quite elaborate measures are taken such as frequent cleaning of the units to avoid the fouling that plagues scrubber operation. The great success stories are most often those involving scrubbing of low sulfur coals.

To be sure, there are some reasons why we cannot discount totally EPA's arguments about the potential levels that scrubber performance could attain. Existing policy making has been designed to maximize the chance that scrubber technology would fail to develop rapidly. The stress on unrealistic penalties such as shutting down all the power plants in a region has been a powerful incentive for those subject to air pollution regulations to devote more effort to securing delays of implementation than to working out compliance technologies. The federal government could have, but did not, offset this reluctance by mounting its own program for promoting the development of scrubber technology. It is possible that with greater pressures to use scrubbers exerted by the combination of BACT and the EPA decision to impose fines equal to the cost saving produced by noncompliance, scrubber technology might attain higher levels of reliability. However, the inherent technical problems with scrubbing apparently are quite formidable. Therefore, the feasibility of attaining high reliability even under a more favorable climate cannot be taken for granted. We can be even less sure that perfecting scrubbing is the preferable approach.

With these technical facts in mind, we can turn to the response of electric utilities to air pollution regulations and the response of policy makers to utility action. Shifts in fuel choice, of course, were altered by other forces. Overall, what we had was the virtual disappearance of coal use by any electric power plant from Virginia to New Hampshire (the northern limit of the coastal coal market at the time) that had easy access to imported oil (namely, a location to which water borne shipment was possible). The shifts initially were inspired by the low oil prices of the late 1960s and were extended by the pressure of increasingly severe air pollution regulations. The massive rise in oil prices has done little to reverse this shift from coal. Local pollution control agencies often seem to resist any efforts to reintroduce coal and in any case, the tearing out of coal handling facilities, the dedication to other uses of the land on which the coal has been stored, and the high costs of fitting scrubbers to what are now plants with short remaining lives and lower operating rates has made the economics of conversion unattractive. Conversely, the shrinkage of natural gas availability has caused electric utilities in much of the West Central and Rocky Mountain portions of the U.S. to shift to coal. This increased dependence on coal occurred in every Rocky Mountain state but Wyoming (which was already predominantly dependent on coal) and such West Central states as Minnesota, Iowa, Missouri, Kansas, Nebraska, and Texas. (See Edison Electric Institute and National Coal Association data reports.)

Thus, air pollution regulations and other factors caused a westward shift of coal markets. A more critical consideration was that in the East Central markets that have traditionally been the principal ones for the coal industry, many consumers began to look at low sulfur coal from the Great Plains as the preferable source of fuel. Not only did existing plants as far east as Ohio begin use of western coal, but utilities in Michigan and Indiana announced that they would build plants to use western coal.

BACT apparently was introduced at least as much to slow the move to western coal as to produce greater reductions of air pollution. Those favoring such reductions clearly benefited from the support of opponents of surface mining and proponents of eastern coal. As suggested above, it proved quite difficult to define BACT in a manner that satisfied all the interest groups involved. EPA has been pressured by the Department of Energy to set the rules in a fashion that partially preserved allowing use of western coal as a compliance option. Fears arose that the upper limit on emission may be defined in a fashion that precludes the use of many midwestern coals. The rules issued allowed some scope for partially scrubbing low sulfur coals and lessened the threats to midwestern coal.

Given that scrubbers are the only feasible way at present to meet the EPA definitions of BACT and given the reservations expressed above about scrubber performance and cost, the effects of BACT may be quite different from what EPA expects. EPA's reliability and cost assumptions imply that the expected prevention of a shift to western coal will occur under BACT. If it turns out that it is actually significantly cheaper, because of the higher reliability, to scrub low sulfur coals, a quite different outcome might actually occur.

Sulfur oxide pollution control policies, therefore, have created considerable uncertainty about which coals, if any, can be burned by electric utilities and other large-scale fuel users. Concern exists that severe further problems will be created when policymakers seek to impose more severe nitrogen oxide regulations and controls on trace element emissions.

Before discussing the other policies affecting coal, it should be noted that the U.S. government is the owner of substantial coal resources west of the Mississippi. Policies toward the development of federally owned coal can arise out of the normal administrative practices for leasing, from new legislation applicable to federal land, or from policies designed to control the problems arising from coal mining on all lands.

Before plunging into the appraisal of policy, we may note some of the complexities of land ownership in the West. First, the federal government, the states, Indian tribes, and private parties, particularly railroads, own coal rights with these holdings often intertwined. In many cases, to develop an efficient sized mine, coal rights must be secured from several different coal owners. The most celebrated element of this problem is checkerboarding between federal and railroad lands--so called because every other tract around the rights of ways of western railroads was granted to the railroad with the other tracts staying in federal hands. Thus, a map of federal and railroad holdings resembles a checkerboard. A further complication is that mining laws were devised effectively assuming underground mining. The federal government and other landowners chose to sell surface rights while retaining ownership of the coal. With the predominance of surface mining, problems now exist of securing consent of the surface owner as well as the coal owners.

Four critical elements may be distinguished in western coal policy. First, in 1969, the National Environmental Policy Act included the provision requiring an environmental impact statement on all major federal actions. The minimum implication of this requirement is that expensive, time consuming efforts are required to prepare such statements. In addition, it proved that numerous ambiguities existed in the law. Extensive litigation was required to decide what decisions were major and what constituted adequate review. Having perused numerous environmental impact statements, I would argue that the federal agencies have tried to provide the minimum possible information and ultimately have managed to comply with the formal requirements without providing truly insightful overviews of the issues. Another problem about the environmental impact statement process is the potential to abuse the right to litigate. In short, considerable question exists about the efficiency and efficacy of the requirement that environmental impact statements. However, what is critical here is that coal leasing must be supported by environmental impact statement. Indeed, a whole range of statements are prepared. The overall leasing program has been the subject of a protracted effort to prepare an environmental impact statement. Statements are prepared for individual leases (with the practice as of 1979 being to combine several leases in one report). An intermediate level of reports for various regions is being developed.

The second important development was the 1971 administrative decision by Secretary of the Interior Rogers Morton to impose a moratorium on coal leasing. This was in response to allegations that more coal had been leased than was "needed". The need argument proved in retrospect to be a manifestation in the coal realm of the widespread concern over windfall profits in energy production. There is no real cost to society and possible benefits, given the complexities of securing a lease, for allowing substantial amounts of coal to be in the hands of those capable of actually exploiting the coal (or even able to transfer the coal rapidly into the hands of potential miners). The problem is whether the government can adequately insure that the distribution of the income from exploitation meets the fundamental criterion of current public policy that few economic rents remain in the hands of those holding the leases.

The profit sharing issue is a classic problem in mineral policy making. The basic source of the difficulties arises from the economic heterogeneity of mineral deposits. The variations in mineral quality and the differences in the ease of mining and transporting the material to market create major differences in competitive position. Thus, for any given mineral, one can define a hierarchy of deposits according to their relative attractiveness (a phenomenon crudely represented in every elementary economics textbook by the upward sloping supply curve). Rarely can supply be equated to demand by use of only the economically most attractive mines. It is usually necessary to increase market prices to sufficiently high levels that it will be profitable to operate less satisfactory deposits. In technical terms, market equilibrium occurs at a price at which the quantity produced equals the quantity demanded and this price is sufficient to insure the profitability of the economically least attractive deposit in use. Clearly, if prices rise to make the worst operating deposits barely profitable, better ("intramarginal") deposits will be earning "economic rents"--profits greater than the bare minimum needed to justify the creation and maintenance of the operation. It has been a worldwide tradition that, since these profits arise because of lucky access to bounty created by nature, they should be taken away from the mine or landowner and transferred to the general public. Note that whether the transfer is called a royalty, lease payment, tax, or whatever is a purely legal distinction; what counts economically is the form the payment takes.

Unfortunately, although the basic principle is widely accepted, its implementation involves many problems. The definition of the appropriate "public" and how to reward it are often causes of considerable dispute. In particular, a basic question arises about the extent to which the region in which mining occurs deserves special consideration. To the extent that such local claims are accepted, a choice exists between (1) surrender of the authority to capture the economic rents to the region and (2) retention of this power by the federal government with final transfer of its receipts to the states. Moreover, complex technical problems arise in imposing a system of collecting the rents in a fashion that meets all the goals that are generally defined. Such goals include securing all the rents, avoiding distortion of output, administrative simplicity, and allowing wide access to the land to a sufficient number of procedures to prevent monopoly. A rich literature shows that these objectives are often in conflict. For example, a simple tax such as a uniform sales tax fails to tax the more profitable ventures more severely (see Steele, 1967 and Mead, 1969).

At least five potential claimants exist for whatever economic rents may arise. The mine operator will seek to keep as much profit as possible. The federal government is clearly seeking to charge enough for access to the coal lands to insure it receives the economic rents. However, the states would like to share in the largess. Montana imposed a 30 percent tax on coal, and certainly the increase legislated by the U.S. Congress in 1976 of the states' share of the money initially collected by the federal government was in response to state pressures for a larger share. As implied above, the surface rights to much of the coal bearing lands are in private hands, and considerable concern exists about efforts of those owning surface rights to secure their share of the economic rents. Finally, Zimmerman (1975) has suggested the railroads possess sufficient monopoly power that they will seek a substantial share of the economic rents. Clearly, the danger exists that total claims will be excessive. Although strenuous pressures on the

U.S. government to secure maximum income from its coal lands may preempt action elsewhere, the question of rent sharing could, as it has done in Canadian oil, thwart industry expansion. In any event, numerous theories exist about how, with adequate knowledge about the resources and the potential demands for them, competitive bidding for leases will lead to payments for leases that equal the present value of the economic rents. At the very least, it must be recognized that noneconomists are quite likely to fail to understand the workings of this process. Those taking leases will, in part, be buying for exploitation in the distant future. Here the government trades a lower earlier income, on which it earns interest, for the higher payment that would be secured if the lease were delayed. Unfortunately, the difference in payments is more apparent than the interest-earning benefits of the earlier sale. More critically, both laymen and economists tend to feel that the markets are imperfect and that this imperfection will lead to significant underbidding. Actually, all existing markets are imperfect in the sense that they at best adopt ad hoc techniques whose correspondence to the idealized institutions assumed to exist in pure theory is quite unclear. We have become increasingly conscious that the theory is itself deficient in recognizing that ideal institutions may be inefficient to establish. The costs of running them may exceed the benefits produced. Thus, we cannot be sure whether our actual institutions are sensible efforts to economize on organizational resources or are truly seriously deficient for promoting economic efficiency. In the absence of fully satisfactory measures of the impact of public policies, the issues are generally debated on purely ideological grounds. What we can say is that the lease program for oil, as has been shown in numerous studies, captures a substantial amount of economic rent. However, questions can fairly be raised about whether similar conditions would apply to a coal leasing program--particularly one that allowed long-run holdings of coal rights.

A more fundamental concern relates to the neglect by those who propose limiting coal leasing to that which is needed to the numerous costs that are imposed. As discussed below, the available evidence suggests that leasing has become a long lead time operation. This leaves policymakers facing the problem noted above for electric utilities--of making commitments for periods about which accurate forecasting is impossible. Concern must be expressed over the dangers of limiting too vigorously the degree of leasing. As is so often the case, a particular problem is that close control over leasing could aggravate the difficulties in the other area--competition in the energy markets--that has been a major source of fears about leasing policies.

Fears have been expressed that control of the coal will accumulate in the hands of a few companies. As a result, at the very least, these companies will collude to control coal prices. It is further argued that, if these landowners are oil companies, their collusion will be designed to limit competition between coal and conventional sources of oil and gas. Thus, the fear is that too little coal will be developed too slowly.

Critics of this argument note that, given the large number of oil companies and others interested in western coal and the comparatively simple technologies involved in strip mining, a coal monopoly seems unlikely. The rapid entry of new nonoil or coal producing firms such as Utah International and the Pacific Power and Light-Kiewit group into large-scale production supports this view.

The overall issue is whether an energy monopoly is emerging within the U.S. economy. The concern was stimulated primarily by a series of acquisitions in the late 1960s of major coal companies by other firms, particularly oil companies. Conjecture arose as early as 1969 that the oil companies were insuring reserves for the impending process of massive manufacture of synthetic fuels from coal (U.S. Federal Trade Commission, 1969, esp. chapter 8). When coal prices started rising sharply in 1969, a number of observers, notably the American Public Power Association, charged that the increases were part of a conspiracy on the part of the oil companies to effect a general rise in energy prices. A number of Congressional hearings were held on the subject; for example, U.S. House of Representatives, Subcommittee on Special Small Business Problems of the Select Committee on Small Business, 1970 and 1971. The American Public Power Association's views can be found in both hearings. A particularly accessible, more recent, well-publicized expression of the concerns appears in the final report of the Energy Policy Project of the Ford Foundation.

At the very least, we can argue that the charges have been unsubstantiated. A more recent (1974) Federal Trade Commission (FTC) study of competition in energy concludes that while "concentration" (the percent of the market supplied by the largest firms) has been rising, this is due almost entirely to increased concentration in production of individual fuels. Very little of the change is due to diversification. The FTC concludes that the market share of the 20 largest firms in energy production would have fallen from 57.0 percent to 54.5 percent if the companies' coal and uranium operations were excluded. (For the top eight, the change would be from 37.8 to 37.0 percent.) The FTC adds that despite the increases, "concentration is low compared to many other industries" (Mulholland and Webbink, 1974, p. 137 and p. 148).

The concern over competition in the coal industry has inspired several different subsequent studies by U.S. government agencies. One of the earliest in terms of both when it was started and when a draft was finished was that of the Federal Trade Commission (1978a and 1978b). In its draft version, it concluded that the coal industry was highly competitive and no competitive danger existed because of the involvement of oil companies and others in the industry. This result apparently was unsatisfactory to someone because the FTC first commissioned a critic--John Wilson (1978), long known as a proponent of the proposition that the energy industries are inadequately competitive--to appraise the report. Wilson's principal criticism was that the original report overstated the degree of competition by including reserves owned by the federal government that had not been leased in the universe of total available reserves. He felt it was more appropriate to compute shares of lease holdings by private firms to the total already in private hands. This approach necessarily raises the shares of the largest reserve owners since one compares an unchanged numerator to a smaller denominator. However, the recalculation is more a measure of the threat to competition imposed by the lease moratorium than an indication of an inherent monopoly problem. In any case, the Federal Trade Commission issued a revised final report on competition in coal in early 1979. The data in the report differed slightly, but the tone was radically altered. A summary discussion was added of the criterions various economists have proposed for inferring various degrees of danger associated with various market shares for the largest firms. Where there was evidence that one of these danger points had been reached, this was noted. More critically, the paragraph in the conclusions chapter of the report that summarized the analysis of market shares was radically changed. The prior statements about the absence of monopoly problems was replaced by a statement describing the concentration levels as "low to moderate"...except in the Midwest "where it was quite high".

Similarly, although only minor alterations of the data themselves rather than alterations of the tone of the text were undertaken in the revision of the chapter on the participation of oil companies and other types of firms in the coal industry, the revised report deleted the paragraph from the conclusions of the draft report that argued that this participation caused no threat to competition.

Two other reports on competition in coal--that of the General Accounting Office (1977) and the Department of Justice (1978)--were much more sanguine about the state of competition. Both concentrated their concerns on the small southwestern market (Arizona and New Mexico) where activity when the reports were compiled consists of a very few very large mines and thus where present concentration rates are quite high. The Justice reports suggested that considerations such as the sophistication of the buyers, freedom of entry, and competition from other areas could preclude monopoly in the future. The Department of Justice raised two other concerns. First, it identified "bottleneck" stages in the nuclear fuel cycle--conversion of uranium oxide to uranium hexafluoride--the gaseous form in which it is enriched--and the forming of the enriched uranium into pellets. Although the Justice Department does not say so, the leading firms in conversion are Kerr McGee and Allied Chemical; the fabrication is dominated by the four firms--General Electric, Westinghouse, Combustion Engineering, and Babcock and Wilcox that produce reactors; Exxon was the only other producer in 1975. This was considered the only area of markedly dangerous concentration levels in the energy industry, and thus extra limits on the amounts of coal leasing by firms in these sectors were proposed. The other concern was that railroads might exercise monopoly power if they were allowed to exploit their coal. The point of this argument was somewhat obscure. It appears that the concern was over price discrimination arising that would cause buyers closer to the western coal fields with less economic access to midwestern coal because of the high transportation costs to pay a higher f.o.b. price for coal than buyers nearer the midwestern coal fields. It is quite unclear just what the implicit argument may have been. It would seem that the monopoly power, if any, that could permit discrimination would be that of the railroad in railroading. The report denies that the railroads or anyone else had a monopoly position in coal production. More critically, since the railroads are certainly not the only coal owners, any monopoly in coal that existed should be attacked generally and not by looking at the other activities of the owners which have not been shown to correlate with monopoly power in coal. It is rather difficult to construct a situation in which coal ownership by railroads is a more feasible way to extract monopoly rents than rate discrimination. The railroads would have to force local customers to buy railroad coal to get railroad delivery and at the very least this would seem to violate the Clayton Act and cause a furor among regulatory agencies. Further, offsets would be provided by the ability to construct facilities at minemouth; in some cases, playing railroads off against one another would be possible.

In contrast to these basically optimistic views on competition, the Tennessee Valley Authority has been arguing, ever since its coal costs started rising in the early 1970s, that it is a victim of monopolies in the energy industry. TVA's lawyers prepared two efforts to document this contention (see U.S. TVA, 1977 and 1979). The reports suffer from several serious methodological flaws. Considerable confusion is demonstrated over what constitutes the relevant market. The summary in the second report of the conclusions of the first dramatizes the confusion by noting: "It [the prior report] showed that steam coal is a distinct product which is traded in a distinct national market and in four identifiable regional markets..." (the ellipsis consists of the names of the markets). The reports downplay the implication of the charts included that show concentration has been declining since 1970 in the coal industry and when asked the basis of their conclusions, the authors cite a belief that rising concentration implies rising prices. (This justification, moreover, shows up in an Appendix to the second report consisting of responses to questions of a Congressman skeptical of the arguments in the earlier report).

In short, while U.S. government agencies are unwilling to express total disagreement with the members of Congress who have been busily sounding alarms about competition in the energy industries, only TVA has been willing to share the concerns fully.

One can go further and suggest at least three flaws in the arguments that oil company entry into the coal business has been or will be a threat to competition. The first problem is that the argument completely ignores the substantial differences among the characteristics of oil companies. In particular, the argument fallaciously assumes that because many of the companies in the oil industry are giants with worldwide influence and possibly have some perceptible influence on price, all oil companies have this attribute.

This is quite incorrect; many oil companies including most of those who purchased coal companies are in fact relatively small factors in the oil industry. Gulf which in 1977 ranked sixth in U.S. oil production and refinery capacity and is considered "an international major" is the only oil industry purchaser of a coal company that can be classified as a "giant" (Duchesneau, p. 37 and p. 44, and Sowell and Brannon, 1978). Gulf, in fact, acquired its coal company as a by-product of a merger with Spencer Chemical (see Duchesneau, p. 83), and the coal company in question ranked 16th in 1977 U.S. production (see Sowell and Brannon, 1978, p. 163).

In contrast, Continental Oil which purchased the second largest coal producer, the Consolidation Coal Company, ranks much lower among oil companies; it ranked 13th with a 1.9 percent share in 1975 oil production (Sowell and Brannon, 1978, p. 56). The other oil companies with coal production are even less important. Occidental Petroleum which acquired the Island Creek and Maust Coal Companies (with the latter merged into the former which ranks fourth in production), for example, does not even produce or refine oil in the United States.

A second consideration is that at the time of the mergers and even today, the prospects for synthetic fuel were so uncertain and involved so long a lead time that coal needs for synthetic fuels could not have weighed heavily in the acquisition of operating coal companies; the current intrinsic profitability of existing mines would have been the critical consideration. The purchasers were mainly buying ongoing operations, and if their need was for reserves, direct acquisition of reserves would have been a more logical strategy.

A third point is that there are simpler more easily documented explanations of the coal price increase: namely, rising costs and unanticipated demand increases that strained capacity.

The relevance of fears about competition is particularly questionable in the West. Numerous large blocks of coal exist, and the required mining technology is simple enough to allow many firms to enter the industry. What has been particularly striking about the West is that the established coal companies have exercised a far from dominant role. Numerous developments were undertaken directly by electric utilities--notably Pacific Power and Light, Montana Power, and Texas Utilities. Pacific Power and Light has become particularly important. It is engaged in independent operations, acts as the principal partner in a coal-mining consortium operating the mines supplying a mine mouth plant in Washington, and has joined the Nebraska-based construction firm, Peter Kiewit and Sons, in the Decker Mining Company. Another significant entrant has been Utah International. Other newcomers to coal such as W. R. Grace and Sun Oil have undertaken or planned entry. Railroad such as the Burlington Northern and Union Pacific have explored development of their extensive coal holdings. Thus, under a federal leasing program designed to foster competition, the prospects for preventing monopolization of western coal seem considerable. Unfortunately, here too actual policy has headed in the wrong direction because of preoccupation with secondary issues. Obsession with the failure to develop leases has caused pressure for due diligence—rapid development. However, this policy combined with the complex procedures governing leasing has as noted an anticompetitive effect. The net effect of the policy is to limit the number of landholders and thus the number of firms able to compete for business. In effect, the policies create the danger that an artificial monopoly position will be ceded those few who manage to secure the few available leases.

The desire to pause for reflection associated with the moratorium grew into a near paralysis of western coal policy that persists to through 1979. The efforts to get on with a more acceptable leasing program were hit with three threats--law suits alleging failures to comply with the National Environmental Policy Act, the 1975 Amendments to the Coal Leasing Act that complicated the policies towards leasing, and the passage of the federal Surface Mining Act in 1977.

The critical environmental case proved to be that instituted by several environmental groups. The groups alleged that the environmental impact statement justifying the resumption of leasing was inadequate, and in the fall of 1977 the District Court judge hearing the case upheld the complaint on the ground that the need for leasing was inadequately justified and thus insufficient attention was paid the option of not resuming leasing. This decision seems somewhat curious given that the environmental impact statement was for a program whose first step was more precise determination of what leasing was needed and which contained a review of the alternatives to coal development that was somewhat shorter but not substantially different from ones in environmental impact statements that have been approved. The Interior Department in any case resisted the pressures some of its staff exerted to appeal the ruling, agreed to limit leasing to a few so-called preference leases--those needed to remove an impediment to developing or continuing an existing lease, and started preparing another environmental impact statement. The identity of the leases was determined in the settlement of the case the Interior Department formulated with the environmental groups.

Surface mining has been the subject of a far more protracted and vigorous effort to impose stringent controls or even outright bans. The argument for bans is so blatant an example of the inverted logic of so many energy debates that it is worth pausing to review. When proponents of a ban on surface mining are reminded of the health and safety consequences of a surface mining ban, the usual retorts are that relieving underground mines from the competition of surface mines will enable the underground mines to afford adequate safety measures and will create more jobs.

Serious defects exist in the greater-ability-to-spend-money-on-safety argument. What will be done to protect workers will depend on the pressures of regulation and worker attitudes. A ban on strip mining will not enter into the immediate decision about what measures to adopt. What the prohibition will do is possibly ease the effects of whatever measures are selected. Employers must pass on their increased costs to consumers if their firms are to survive. The removal of surface mine competition does ease the ability to pass on the cost increases. However, for this to suffice to prevent significant declines in coal production, the cost rises must be sufficiently moderate that they do not cause a shift to another fuel such as nuclear power.

The job creation argument, which is used in many other cases, is even more pernicious. It is true that, so long as a ban on surface mining leads to an equivalent increase in underground mining, employment will increase. So would the employment of accountants if abacuses replaced computers. However, what makes for economic growth and prosperity is productivity advances. Admittedly, market economies are often unable to shift unemployed workers into more productive activities. However, the Luddite approach of creating jobs by reducing productivity is not a satisfactory way to proceed. The long-run effects are to destroy the ability of the economy to sustain the high level of productivity that makes aid to the unemployed politically feasible.

To be sure, the proposals for a ban have been widely rejected, but much of the effort for the severe controls that have been enacted may have been motivated by arguments similar to those for the ban, and these motives have influenced other coal policies. Nevertheless, a valid case can be made for controlling surface mining although the evidence does suggest that the high level of reclamation being required can only be justified by the non-market effects of surface mining. Strip mining without reclamation can produce land disturbance that residents of and visitors to the area find highly objectionable and which precludes agricultural or recreational use of the land. The pits can be safety hazards, and rainwater washing through the mine can deposit silt and acidic material in waterways. The mining activity may cause upheavals in the social framework of the affected area and put strains on local governments. The problems are a graphic example of what discussions of environmental issues refer to as the "site specific" characteristics of the situation--i.e., that every individual case involves different risks and must be judged on an individual basis.

In particular, quite distinct problems arise in Appalachia outside of Ohio, Ohio and the Middle West, and west of the Mississippi. The nature of strip mining and its damage is naturally quite different when the terrain is hilly, as in most of Appalachia, rather than flat. Both mining conditions and restoration of the land are more difficult in such hilly land. However, a different complication occurs west of the Mississippi; the aridity of the land is such that revegetation can be extremely expensive.

Several studies such as those reported in a 1971 anthology prepared for the old U.S. Senate Interior Committee on Interior and Insular Affairs and a 1977 report by Energy and Environmental Analysis, Inc. have tried to undertake benefit-cost analyses of strip mine reclamation. The universal conclusion is that the easily measurable benefits of reclamation such as restoring the land to other uses fall far short of the estimated costs of a rigorous degree of reclamation. Thus, the policy of imposing such controls is implicitly based on high valuation of avoiding the aesthetic insults, changes in social structure, and strains on local government. (Certainly, many attacks on both Appalachian and western surface mining are presented entirely in terms of the upheavals caused for local communities.)

In any case, individual states have imposed strip mine regulations of various degrees of severity (see Energy and Environmental Analysis, 1976 and 1977a, for a review). The U.S. Congress undertook discussions about surface mining regulations early in the 1970s. It was not until 1974 that a bill was passed, but it and a 1975 successor were successfully vetoed by President Ford. James Plummer (1977) conjectured that this state preemption might obviate federal action. However, in 1977 a federal act was passed and signed by President Carter despite concern the law was inadequately stringent. The federal-state jurisdiction problem supposedly was resolved by granting the states the right to enforce the rules so long as they were as strict as required by federal law. The state control could, moreover, be extended to federal lands although certain powers could not be delegated. The implementation of the law as a whole including the delegation of authority to the states has proved highly controversial.

The Surface Mining Control and Reclamation Act, like most laws, is a complex collection of provisions, including extraneous ones to support university research on minerals. Several regulatory goals exist--supervising ongoing strip mining, restoring previously stripped land, and controlling the surface effects of underground mining. Reclamation of abandoned strip mines is to be financed by a tax on coal mining (underground as well as surface, albeit at a lower rate--fifteen vs. thirty-five cents per ton on surface mines). The law sets up rules for seeking and receiving a permit to mine. Applicants must demonstrate their ability to comply with the law. A bond must be posted to guarantee performance.

The key strip mine reclamation requirements of the Act (Section 515b) were as follows:

1. "maximize" initial recovery so that a second disturbance to recover other seams is avoided;
2. restore land to a condition that allows at least as good a use as that prior to mining with extra effort required if the land is considered prime agricultural land;
3. except where impractical, restore land to the original contour;
4. stabilize areas to avoid erosion;
5. segregate and preserve the quality of topsoil or a subsoil of better quality than the actual topsoil;
6. avoid disturbance of hydrologic balance with special emphasis upon alluvial valleys in the West (roughly valleys structured so that disruption of water flow would interfere with farming);
7. revegetate the reclaimed land.

The state governments are authorized to prohibit strip mining on the basis of both specific hazards such as the danger of creating floods and mere incompatibility with land use plans. The secretary of the interior is required to prohibit new mines in national parks and other classes of federal lands, has authorization to make prohibitions using the criterions the states may employ, and must consider private requests for bans. The law requires that when the federal coal rights were retained when the surface was sold, the surface owner must give written permission to mining. Moreover, if substantial opposition to strip mining exists among surface owners the secretary is encouraged to prevent the mining. These provisions end with the cryptic phrase "nothing in this section shall be construed as increasing or diminishing any property rights by the United States or by any other landowner."

Just what all this means is, of course, controversial. An appraisal of an earlier bill by ICF, Inc. (1977) suggested that the impact could be small unless interpretation was very strict. The coal industry generally expects the worst, recalling that past laws have been interpreted as severely as possible, and notes that officials of the Interior Department as of 1977 are dedicated to particularly stringent environment regulations.

All this remains to be tested, but the language of the law involves the ambiguities, complexities, and economically invalid concepts that marred so many prior energy bills. To pick an obvious point, it is hard to determine how you can avoid affecting property rights by the surface owner protection clauses. The best use of land has no economic meaning. We have the basic need for a federal-state accord on policy complicated by various provisions for intervention by surface land owners and other parties. Thus, the potential for administering the law in a highly restrictive fashion appears considerable and the coal industry indeed has criticized the regulation actually promulgated as being overly restrictive.

The new leasing amendments became law in August 1976, when Congress voted to override President Ford's veto. The law called for developing a comprehensive plan to guide leasing in the Interior Department, requiring operators to submit detailed mining and reclamation plans within three years of acquiring the lease. The law also called for a federal program to explore for coal reserves, a ten year limit on holding inactive leases, increasing the states' share in revenues from 37.5 to 50.0 percent, and upper limits on the size of both individual leases and total holdings (although those who had leased more coal than allowed could retain the leases) (U.S. Congress, Public Law 94-377, 1976). Given the moratorium on leasing, the slow pace at which action proceeded prior to the law, and the new strip mine bill, it it difficult to guess what effect all this will have on coal.

A U.S. government task force has charted the net effect of all the regulations affecting leasing, and as far as I can tell after winding my way through the four gigantic charts (each of which more than covers a large desk), once leasing resumes, it would take a decade to move from initiating a lease sale to production. In short, production controls have imposed two severe costs on the coal industry--higher direct costs and the cost of delay.

Thus, health and safety regulation is just one regulatory issue affecting the future of the coal industry. We may conclude the overview of regulation with a summary discussion of the issues associated with the Coal Mine Health and Safety Act. The federal Coal Mine Health and Safety Act passed in late 1969 mandated considerably more stringent requirements. The act had several basic elements. Also in 1973 regulation was moved from the Bureau of Mines to a separate agency, the Mining Enforcement and Safety Administration (MESA), originally part of the Interior Department but transferred in 1977 to the Department of Labor. Second, MESA was empowered to increase radically the number of people employed as mine inspectors. Third and most basically, stricter regulations were imposed on every step in mining where harm to health and safety could occur. Fourth, a provision was made to aid those suffering health damages produced by working in a coal mine.

The rules included a wide variety of stricter standards for what equipment might be employed and what safety features must be used on this equipment; drivers of mobile equipment, for example, had to be protected by canopies or other covers. Stricter lighting and roof support rules were imposed. Mines were to be better ventilated. Higher levels of research on better ways of protecting health and safety and increased worker training were also required.

The Health and Safety Act is best interpreted as part of a broader development--the emerging recognition by coal miners of the dangers of their occupation. For the first quarter century after World War II, an aging labor force that felt trapped in the industry was fairly passive about the hazards. Retirements and industry expansion necessitated attracting new workers. These new workers have clearly been much more insistent about securing their demands in health safety and other realms. Pressure for the 1969 act was only one of several manifestations of this new attitude. In addition, pressure has been exerted on the United Mine Workers to bargain more aggressively. The coal fields have been plagued with an upsurge of wildcat strikes over health and safety and other grievances including issues totally unrelated to the coal industry such as gasoline shortages and school textbook controversies.

A plausible case can be made that worker responses were far from the best possible. Certainly, the problems of the United Mine Workers in 1977 are clearly distressing. The union's professional staff became alienated from the union's president and the rift left the union without experienced staff during a bargaining year. The former staffers and others accuse the union president of losing control of the union. Support to these views has been provided by the difficulties in controlling wildcat strikes.

Such wildcat strikes appear an inefficient way to express frustrations. Many coal producers contend the Health and Safety Act regulations were an inefficient way to deal with the problems. Whatever the truth of all this, the basic difficulty that coal mining is hazardous will not easily vanish. We may or may not find better ways to deal with the problem, but whatever we do appears unlikely to reverse quickly the upward pressures on costs caused by worker demands for protection from or compensation for these risks. These pressures have caused both sharp wage increases and declines in output per man-day in underground mining in the 1969-1976 period, and neither trend shows much sign of disappearing. In later sections we deal with this issue.

A Note on Sources

This section was drafted relying heavily on consultation with industry and government sources, regular reading of The New York Times, Wall Street Journal, Energy Users Report, Energy Daily, Coal Week and Coal News; examination of critical laws, and following the literature closely. Specific references are limited to material uniquely relevant. Examples of the multiple sources for other points are in the bibliography for the section.

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Simulating the Effects of The Coal Mine Health and Safety Act

by

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The impacts of the Coal Mine Health and Safety Act of 1969 have inspired considerable controversy. The implementation of the Act occurred simultaneously with other forces that may also have adversely affected worker productivity. Formidable problems, particularly the absence of satisfactory data, hinder the determination of the impacts. As one possible approach to analysis, the Underground Generalized Materials Handling Simulator (UGMHS), (see Manula and Bouillot, 1975) was employed as the key element in an analysis of the effects of the Act.

The Simulator determines output of a mining section given information on mining conditions and operating practices. To implement an analysis, it is necessary to have adequate data on these influences. More critically, a major impact of the Act is in increasing manpower requirements--principally in the form of an increase in the number of support workers needed (one man had to be added to the face crew. For purposes of analysis, the non-Act manning include the additions mandated by UMWA contracts). This impact is one on which only limited information is available. This problem of data deficiency is handled here by considering the implications of the impacts of increases in labor requirements considerably smaller than those asserted by our sources.

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The basic element of our work was to simulate the behavior of "representative" mine sections in each of several areas--principally in Appalachia. Anyone vaguely familiar with coal mining is aware that the typical mine is a dubious concept. However, the complexities of simulation are such that it was practical only to run a few cases. Suboleski and Manula independently had undertaken a survey of 326 mining sections using placechanging milling type continuous mining machines of which 305 were in Appalachia as follows--West Virginia (60), Virginia (65), Pennsylvania (92), Ohio (33), and Eastern Kentucky (55). It was decided that these data would be used to determine the mining conditions prevailing in each of these five regions. The average value in each region for each critical variable, as determined by the survey, was used in the simulations. Output per section was simulated both for operating practices under the Act and with the removal of selected requirements imposed by the Act. Table 1 presents the assumptions employed in defining these typical sections.

The critical part of the simulations were the adjustments for the provisions of the Health and Safety Act. Attention was limited to three effects--increased checking for methane, more frequent advance of cloth to improve ventilation, and increased mechanical delays. The last effect is handled by assuming that under the Act delays are 35 minutes per shift instead of the 18 minutes prevailing without the Act. Methane checks involve interrupting production every twenty minutes under the Act. Without the Act, the tests were required only once every half hour; this time generally coincided with the machine cycle time. Thus, production was not interrupted. The requirement under the Act to advance line canvas after every 10 foot advance of the mining machine contrasts with a no Act assumption that the moves occur only at the end of a cut. Roughly, this Act means turning a single cut into

Table 1

Physical mine characteristics by state for 1975

	Pa.	W. Va.	E. Ky.	Ohio	Va.
Seam thickness (inches)	65.00	71.00	61.31	60.36	60.28
Seam depth (feet)	475.54	727.00	630.00	340.63	814.62
Distance between entries (feet)	72.00	84.00	65.00	54.00	73.00
Distance between crosscuts (feet)	90.00	76.00	80.00	66.00	86.00
Cut width (feet)	18.00	17.00	19.00	17.00	19.00
Cut length (feet)	18.00	18.00	18.00	18.00	18.00
Floor hardness 1=hard, 5=soft	2.35	2.42	1.78	2.71	2.95
Grade (percent)	2.02	1.30	2.86	0.67	1.82
Dip (percent)	2.19	1.71	2.15	1.93	1.91
Bolt length (feet)	5.51	5.18	4.36	6.30	4.95
Number of bolters	1.14	1.47	1.71	1.55	1.82
Parting (inches)	7.07	6.47	2.53	6.30	6.43
Number of entries	6	5	7	5	5
Shuttle car payload (tons)	5.08	6.64	5.74	6.04	4.46
Unusual delay (minutes)	42.06	18.98	17.36	19.76	43.46
Crew travel time (minutes	28.90	20.86	24.82	22.14	29.59
Loading rate (tons per minute)	3.79	5.65	5.79	5.49	3.62
Cutting rate (tons per minute)	4.10	5.15	4.78	5.08	3.35

Source: Private communication with S. Suboleski.

two steps and performing two line advances where only one would have occurred in the absence of the Act. The methane checks reduce available working time by 20 to 24 minutes per shift; the line canvas advances, 44 to 61 minutes.

The net effect on output per section in tons is as follows:

	Pennsylvania	Ohio	Virginia	W. Virginia	E. Kentucky
Act	280	251	213	290	331
No Act	338	320	290	329	391
Act as Percent of No Act	84	78	73	88	85

Thus, the Act produces a 12 to 27 percent decline in output per section with a simple unweighted average of 18 percent.

A trickier question is the impact of the Act on manning. The estimate initially provided us by an experienced consultant was that the Act had added one worker to the face crew and increased the ratio of support workers to face workers from one to one to two to one. However, the U.S. Bureau of Mines model mine studies which all seem to assume post Act manning requirements indicate current ratios closer to one to one. As shown below, other information suggests that manning changes were a minor effect of the Act.

In the course of the analysis, an attempt was made to estimate the cost impacts of the Act using the simulations and other information. It was assumed that the Act raised manning (including support personnel) from 20 to 30 men per section and increased supply costs by thirty percent and power costs by 23 percent. Various other costs were assumed unaffected by the Act and estimates by Suboleski and Manula of such costs were used. Using a formula relating capital costs per ton of annual capacity to tons per man day, estimates were devised of the required capital investment. The methodology developed by the

U.S. Bureau of Mines was used to convert the capital cost into a required before tax cash flow per tons. (The Bureau's methodology takes account of the fact that the income tax laws divide into three parts the gross receipts available to repay with interest the initial investments. In particular, one portion is called depreciation, another depletion, and the third taxable income, and the USBM has developed ways to treat the implications of this classification). It was deduced that the percent reductions in cost if the Act had not been in force were as follows:

Pennsylvania	36 percent
West Virginia	25 percent
Eastern Kentucky	28 percent
Ohio	30 percent
Virginia	43 percent

Since these calculations involve information not supplied by the simulator, it seemed desirable to make some sensitivity analyses to see how the results were affected by alternative assumptions.

Table 2 provides a set of labor cost multipliers based on the range of shift productivity decline factors determined by the simulations with a range of crew size increase factors that arbitrarily start with a ratio of 1.1 and range up to the 1.5 ratios our sources considered the most realistic. We can undertake several calculations with these multipliers. The simplest is that done in Table 3 of calculating the reciprocals which represent the productivity decline ratios.

As the next step, we calculate a range of total cost differences with and without the Act. The differential labor costs are computed on the basis of the factors from Table 2. Required income from capital is assumed to be

Table 2

Labor Cost Multipliers Associated with Selected Combinations of Section Productivity Declines and Labor Requirement Increases Under the Coal Mine Health and Safety Act

Ratio of Act Manning to Non Act Manning	Ratio of Non Act Output Per Section to Output Per Section Under the Act		
	.80	.85	.95
1.10	1.38	1.29	1.22
1.20	1.50	1.41	1.33
1.30	1.63	1.53	1.44
1.40	1.75	1.65	1.56
1.50	1.88	1.76	1.67

Table 3

Outputs Per Man Day Under Act as Ratio of Non Act Output Per Man Day

Ratio of Act Manning to Non Act Manning	Ratio of Non Act Output Per Section to Output Per Section Under the Act		
	.80	.85	.95
1.10	.73	.77	.82
1.20	.67	.71	.75
1.30	.62	.65	.69
1.40	.57	.61	.64
1.50	.53	.57	.60

proportional to section productivity. Rises in materials costs are ignored. The rise in total costs could be computed in two fashions representing the two extremes of possible responses to differential cost changes. At one extreme, one could heavily substitute the relatively less expensive factor for the more expensive one. A standard economic concept for treating this is that of the "Cobb Douglas" production function whose critical property for our purposes is that the proportional share of each input in costs is always constant. The opposite extreme would be one of zero substitution and thus the inputs rising most rapidly in cost become a greater proportion of costs. Since the second method is simpler, it is used here.

Finally, two quite radically different proportioning of costs emerge from various cost studies. Work by the U.S. Bureau of Mines suggests that the relative shares are about 40 percent labor, 30 percent capital, and 30 percent other. Charles River Associates using census data suggests shares of 59 percent for labor, 12 percent for capital, and 29 percent for other. I here adjust these shares to 60, 15, and 25 percent. As a third alternative equal shares are considered (see Table 4).

The exercises suggest that it is unlikely that the costs would be more than 90 percent of those with the Act if the Act did not apply and could easily be 80 percent of the costs with the Act. On top of that, the estimate of $1.00 per ton extra supply cost figure may reasonably be added.

We have been able to secure access to a few carefully done efforts of mining companies to simulate the effects of the Act on their mines. These data suggest that due to compensating errors our initial estimates of cost increases are reasonable. The company case studies suggest we grossly underestimated the declines in shift productivity which actually tended to exceed 30 percent. However, the studies indicate that, on balance, cost changes are roughly inversely proportional to production declines. Total costs change little under the Act because reduced supply costs, union welfare payments, and royalties associated with lower output offset increased expenses due to the Act. (The key problems here are how to interpret the royalty and welfare payments. If, as some allege, these are transfers of excess profits to workers and landowners, the cost declines are really profit declines and should not be counted. Conversely, if the payments are real resource costs, the costs count. In practice the magnitudes are so small that the effect of alternative treatments is minor). In any case, this would imply that costs would be 70 percent or less than current levels if the Act did not apply.

The next key question is to what we may relate these costs. What we want to look at are the social costs of the policy. This requires unavailable information about the average required selling price of the 224 million tons of coal deep mined in Appalachia in 1975. We, of course, have no data on what that cost might be. We do have an upper limit. We can compute from Bureau of Mines data that the weighted average realized price of that coal

Table 4

Cost Change Rates for Zero Substitution Case

Case I
Labor 40 percent, Capital 30 percent, Other 30 percent

	Labor Cost Reduction Factor	Capital Cost Reduction Factor	Total Cost Reduction Factor
Factor	.73	.80	
Factor times weight	.29	.24	.83
Factor	.67	.80	
Factor times weight	.27	.24	.81
Factor	.62	.80	
Factor times weight	.25	.24	.79
Factor	.57	.80	
Factor times weight	.23	.24	.77
Factor	.53	.80	
Factor times weight	.21	.24	.75
Factor	.77	.85	
Factor times weight	.31	.26	.86
Factor	.71	.85	
Factor times weight	.28	.26	.84
Factor	.65	.85	
Factor times weight	.26	.26	.82
Factor	.61	.85	
Factor times weight	.24	.26	.80
Factor	.57	.85	
Factor times weight	.23	.26	.78
Factor	.82	.90	
Factor times weight	.33	.27	.90
Factor	.75	.90	
Factor times weight	.30	.27	.87
Factor	.69	.90	
Factor times weight	.28	.27	.85
Factor	.64	.90	
Factor times weight	.26	.27	.83
Factor	.60	.90	
Factor times weight	.24	.27	.80

Table 4 continued

Case II
Labor 60 percent, Capital 15 percent, Other 25 percent

	Labor Cost Reduction Factor	Capital Cost Reduction Factor	Total Cost Reduction Factor
Factor	.73	.80	
Factor times weight	.44	.12	.81
Factor	.67	.80	
Factor times weight	.40	.12	.77
Factor	.62	.80	
Factor times weight	.37	.12	.74
Factor	.57	.80	
Factor times weight	.34	.12	.71
Factor	.53	.80	
Factor times weight	.32	.12	.69
Factor	.77	.85	
Factor times weight	.46	.13	.84
Factor	.71	.85	
Factor times weight	.43	.13	.80
Factor	.65	.85	
Factor times weight	.39	.13	.77
Factor	.61	.85	
Factor times weight	.37	.13	.74
Factor	.57	.85	
Factor times weight	.34	.13	.72
Factor	.82	.90	
Factor times weight	.49	.14	.88
Factor	.75	.90	
Factor times weight	.45	.14	.84
Factor	.69	.90	
Factor times weight	.41	.14	.80
Factor	.64	.90	
Factor times weight	.38	.14	.77
Factor	.60	.90	
Factor times weight	.36	.14	.75

Table 4 continued

Case III
Equal Shares

	Labor Cost Reduction Factor	Capital Cost Reduction Factor	Total Cost Reduction Factor
Factor	.73	.80	
Factor times weight	.24	.27	.84
Factor	.67	.80	
Factor times weight	.22	.27	.82
Factor	.62	.80	
Factor times weight	.21	.27	.81
Factor	.57	.80	
Factor times weight	.19	.27	.79
Factor	.53	.80	
Factor times weight	.18	.27	.78
Factor	.77	.85	
Factor times weight	.26	.28	.87
Factor	.71	.85	
Factor times weight	.24	.28	.85
Factor	.65	.85	
Factor times weight	.22	.28	.83
Factor	.61	.85	
Factor times weight	.20	.28	.82
Factor	.57	.85	
Factor times weight	.19	.28	.81
Factor	.82	.90	
Factor times weight	.27	.30	.91
Factor	.75	.90	
Factor times weight	.25	.30	.88
Factor	.69	.90	
Factor times weight	.23	.30	.86
Factor	.64	.90	
Factor times weight	.21	.30	.85
Factor	.60	.90	
Factor times weight	.20	.30	.83

was around $29 per ton. This number overstates required selling prices in at least two fashions. Realized prices in 1975 undoubtedly were above the required selling prices for many producers (although some might still have had problems passing on costs under long-term contracts). The selling prices moreover are for coal as shipped and in many cases the coal was cleaned and the price includes compensation for cleaning expenses.

The expedient adopted here is to suggest that required selling prices might be considered to range between $15 and $30 per ton. With the lower required selling price and a ten percent cost reduction if the Act had not applied, the cost of the Act is $1.5 per ton or $336 million dollars. With a $30 required price, a 20 percent cost reduction, plus an additional $1 in supply costs, the cost per ton becomes $7 and the total cost $1.6 billion dollars. The numbers based on a ten person per shift manning difference, of course, imply much higher costs. However, a midway figure of around $700/$800 million seems plausible as a best guess. This would be around $3/$3.50 per ton. About a dollar of this would be explicable by the $1 in supply costs leaving $2.00 to $2.50 to be explained by other factors. Numerous plausible combinations of required selling prices and cost reductions would produce such a range of savings.

For example, $2 is 13 percent of $15; $2.50, 17 percent of 15 dollars. If the cost decline were only 10 percent, a $2 decline is consistent with a $20 required selling price; a $2.50 decline with a $25 price.

Thus, in Appalachia alone the Coal Mine Health and Safety Act appears conservatively to have imposed a cost of $700-$800 million per year. If the data from industry sources are considered more plausible, and costs would be at least 30 percent lower under the Act, the costs of the Act would be around a billion dollars if costs averaged $15 a ton in 1975 and double that given a $30 price. Whether the benefits of the Act are commensurate with these costs is something we cannot determine. Thus, we have here a very tentative appraisal. We hope that it will at least provoke some comment that will produce better understanding of the true impacts of the Act.

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II-I

PART II

BENEFIT-COST ANALYSIS
OF
THE COAL MINE HEALTH AND SAFETY ACT OF 1969

By

Louise Chandler Julian

II-I-1

CHAPTER I

INTRODUCTION

Underground coal mining has very high accident frequencies and severity rates as compared to other industries; it is the most hazardous employment in the United States. The Farmington, West Virginia disaster in 1968 in which 78 men were killed focused public attention on the fact of these hazards and raised public concern. To a large degree in response to this, the Coal Mine Health and Safety Act of 1969 (CMHSA), Public Law 91-173, was enacted to improve the working conditions in the nation's coal mines. The Act went into effect in 1970. The legislation contains provisions concerning detailed safety and health requirements, personnel qualifications, and procedures for inspection, among other requirements. The scope of this legislation is much broader than any previous state or federal legislation, and it purports to increase punitive powers over violators.

The CMHSA may also be viewed as part of a broader development, as pointed out by Gordon (1978). This is the increasing recognition by coal miners of the level of danger of their occupation. A younger work force has demanded better working conditions. In fact, the enactment of the CMHSA overlapped with other major changes, some also adversely affecting productivity. Pressures have been increased on the United Mine Workers to obtain demands through more aggressive bargaining. There has been continuing deterioration of worker attitudes and an upsurge of wildcat strikes.

In theory, workers will accept a wage to do a job only if that wage is at least large enough to cover their productive value plus the extra risk they are assuming in that occupation. The miners could have opted to negotiate for higher wages or better mine conditions through their union. However, they must have felt they could get at least equal results by allowing safety to be legislated (Gordon, 1976, personal communication). Perhaps because of the UMW's monopsonistic power, they felt they could get both higher wages and greater safety with government regulation.

There is considerable literature on the theory of risk in employment and safety as an economic good. Oi (1973, 1974) has written on the economics of industrial safety and workmen's compensation, and Chelius (1974) examines alternative methods for industrial accident control from theoretical and empirical premises. Lowrance (1976) has written about the concept of safety and the social context within which safety decisions are made. Employers will allocate resources to create safer working conditions if the lower injury rates reduce costs by at least as much as "safety" costs. Further, workers will provide labor in more hazardous jobs if they are sufficiently compensated through wages and benefits. If there are externalities preventing the true optimum allocations to be reached, such as lack of full knowledge of risk or immobility of labor force, public decision making may enter in. Suffice it to say that the optimum public policy should, in theory, be to provide "safety" just to the point where marginal benefits equal marginal costs including all externalities.

Since the regulation was put into force, there have been significant declines in productivity and output and an increasing trend in man-hours worked in underground mines. The Act places extra men into the mines in generally safer jobs doing work that produces additional safety rather than coal. This factor, the increase in number of men per shift, exerts a considerable negative influence on productivity; this also lowers injury rates in terms of injuries per million man-hours even with the level of safety remaining unchanged. On the other hand, an increase in the number of men in a mine at a given time exposes more to risk. In the event of an explosion or roof fall, the probable number injured in the accident is increased.

Statement of the Problem

From the viewpoint of economic efficiency, there must be offsetting benefits to justify the cost of the CMHSA. Benefits are mainly reductions in fatal and nonfatal accidents and improvements in health. It is of importance to attempt to quantify the costs and benefits to determine whether the expenditure of resources is offset by benefits. That is the purpose of this paper.

Methodology

Linear regression analysis is employed to derive estimations of reduction in productivity and injury rates in underground bituminous coal mines due to CMHSA. The productivity model employed was developed by E.L. Julian (1977). Injury rates studied are fatal and nonfatal rates in terms of man-hours and production. Data are analyzed at the state level for five states - West Virginia, Pennsylvania, Illinois, Ohio, and eastern and western Kentucky, which will be referred to as "states". In 1975, these states produced over 85 percent of the total tonnage of underground bituminous coal (U.S. Department of the Interior, MESA I.R., 1975, p. 82).

The study quantifies only the benefits in terms of improved safety; conclusive evidence as to the magnitude of benefits from improved health standards is not likely to be available for a number of years, due to the nature of black lung disease.

Organization

This work is divided into five chapters. This chapter defines the problem and objectives. In Chapter II, prior work is reviewed, and the models are developed. Chapters III and IV present results of the productivity and injury models, respectively. Chapter V contains summaries of the results of both models. Predictions of the number of fatal and nonfatal injuries prevented by the Act are presented, with average severity values for permanent partial and temporary total nonfatal accidents. Derivation of monetary values of benefits and costs and a comparison of these values is presented.

CHAPTER II

PRIOR WORK AND DEVELOPMENT OF MODELS AND METHODOLOGY

After a literature review, the models for productivity and injury rates are developed in this chapter. The theoretical bases for the models are first explained. Then, variables are defined, and data sources are enumerated. Finally, methods of analyses are explained.

Prior Work

An appraisal of the benefits and costs of the 1969 coal mine health and safety legislation must begin with estimating the actual reduction in injuries, improvements in health conditions and reduction in productivity due to the law alone. In order to achieve meaningful estimates, it is necessary to separate out, as much as possible, factors other than the law which affect safety and productivity. Trend projection and regression analyses can be useful in determining the degree to which changes in injury rates and productivity differed from those which would have been expected from a continuation of past trends without the 1969 legislation. Work of this kind, especially as applied to the benefits of legislation, has been done by several researchers applied to this and earlier coal mine health and safety legislation. On a less rigorous level, some studies have simply compared injury rates after enactment of federal legislation to rates before the legislation to make qualitative statements as to the possible effectiveness of a law in reducing injuries. Some methods and results from pertinent studies are reviewed here.

Christenson and Andrews have published three studies dealing with coal mine safety and federal regulation. In their first investigation (1973), a comparison was made of injury frequency rates in two time periods having different federal regulations. These periods are 1940 to 1952 and 1953 to 1965. In the former time span, the law in effect was the Coal Mines Inspection and Investigation Act of 1941 that gave the power of inspection of coal mines to the federal government but involved no punitive power. To account for the unusually high injury rates during the increased production of the war years, they also used the period 1946 to 1952 to compare with the time period 1953 to 1965. In the latter time period (1953 to 1965) the Federal

Coal Mine Safety Act of 1952 was in effect and gave the Bureau of Mines not only the power of inspection but also the power to close mines in interstate commerce found in violation of the safety code. This law applied only to underground mines employing at least 15 persons underground. The goal of the Act was to prevent disasters, i.e., events causing five or more deaths in a single accident. The purpose of this study was to determine whether injury rates from disasters and injury rates in general declined significantly after the enactment of the 1952 legislation. Christenson and Andrews did not, in this study, quantitatively analyze the effects of factors other than the legislation on injury rates and did not draw any relevant conclusions concerning the effects of the varying levels of federal control on injury rates. The injury rates considered were rates per million man-hours worked and injury rates per million tons of coal produced. Using the former measure of injury rate, an examination of statistics on fatal and nonfatal injuries before and after the 1952 federal legislation suggested to Christenson and Andrews that the overall fatality rate did not decline significantly, although some reduction of disaster fatalities occurred. The total nonfatal injury rate for underground mines declined by around 17 per cent in the latter period (Table 3, p. 68-69). The authors applied the Mann-Whitney test[1] to injury data for deep and strip mines for the two periods 1940-1952 and 1953-1965. The statistical test showed that declines in the total nonfatal rate and in the permanent disability rate were "highly significant", but no significant change occurred in the fatal injury rate. Since the effects of the war years were included in this test, the rates decline more dramatically than for the time periods 1946 to 1953 and 1953-1965.

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[1] The Mann-Whitney test is a procedure designed to determine whether or not two independent samples were drawn from population with the same medians. The null hypothesis is that the two medians are equal, and the alternative hypothesis is that the two medians are not equal (Siegel, 1956).

Fatal injury rates in small mines not covered by the legislation actually declined in the period 1953 to 1965 as compared to 1948 to 1952. Nonfatal accident rates declined in small mines as they did in mines covered by the law, but the rates were generally lower in the small mines in both time periods. Christenson and Andrews suggested this might be due to a difference in reporting nonfatal injuries, with smaller mines possibly overlooking some of the less serious injuries. On the other hand, some contend that small mines fail to report fully on the number of man-hours worked. If this were the case, the injury rates would look higher than they actually are. Obviously, without some widespread validity checks of the data by the Bureau of Mines, these uncertainties cannot be resolved. Using the measure of injury rates expressed in terms of production, the data behave somewhat differently. Both fatal and nonfatal injury rates declined during the 1953 to 1965 time period as compared to 1948 to 1952 for both categories of mine size. The authors say that these declines reflect the rise in productivity in underground mines in the latter time period. There is little difference in the declines of injury rates between mines covered by the regulation and mines not covered by the regulation. Larger mines had lower injury rates, in general, than the mines employing less than 15 people underground. No mention is made of using statistical tests to see if the declines were significant. However, it must be stressed that changes in injury rates, whether significant or not, cannot be attributed only to federal safety regulation unless one can show that all other factors affecting mine safety have remained constant.

Christenson and Andrews suggest that technological change has had an effect on the injury rates in such a manner as to produce a greater proportion of serious injuries. This might help to explain the slight increase in fatal injury rates from the time period 1946 through 1952 to 1953 through 1965. However, contrary to what their theory implies, the permanent disability rate did not rise along with the fatal rate; rather, it declined similarly to the temporary disability rate. Other factors the authors suggest might affect mine safety are physical characteristics of the coal seam and structural geology, differences in degree and type of mechanization, experience, education and age of the miners and state regulatory practices.

In a second study by Andrews and Christenson (1974), a multiple regression analysis was made in an attempt to determine whether significant relationships exist between injury rates and such variables as production technology, size of mine and federal regulatory activity. Thus, the model employed was

$$I = f\ (T, S, R)$$

where I is the injury rate from accidents, T is the technology employed in mining, S is the size of mine and R is federal regulatory activity. The law being investigated was again the Federal Coal Mine Safety Act of 1952. The authors point out that other important factors affecting injury rates were omitted from the model. Some of these factors are physical environment of the mine, characteristics of the labor force, attitudes and priorities of the managerial force and state regulatory activity. For the time period 1940 to 1965 they included a dummy variable for war, taking the value of one for the years 1940 through 1944 and zero otherwise.

To represent the independent variables of technology and mine size, different data sets were tried. For technology of production, three different variables were defined: per cent of coal loaded mechanically, output per man-hour and a "technology index" based on an equally weighted average of the previous two variables. For the size of mine, three variables were also defined: average number of men working per mine, average output per mine and the reciprocal of the number of mines. Since a decrease in the number of mines (increase in the reciprocal of the number of mines) does not necessarily mean that the average size of mine is greater, this seems to be a poor choice as a proxy for mine size. Finally, a dummy variable was introduced to reflect the effects of federal regulation on mine safety; this variable took a value of zero for the years 1940 to 1952 and one thereafter.

Three different injury rates were the dependent variables: fatal injury rates per million man-hours worked in underground bituminous coal mines, nonfatal injury rates per million man-hours worked and nonfatal permanent disability injury rates per million man-hours.

The regression models they present "were selected from a larger number of fitted functions and represent the most favorable results for the different time periods and dependent variables. The criteria for selection were mainly level of R^2 and significance of the regression coefficients" (p. 370). For fatal injury rates, the results for the time periods 1940 to 1965 and 1945 to 1965 indicate that increasing the per cent of coal loaded mechanically and the size of mine (average number of men working per mine) both tend to lower the injury rates. Both of these variables were significant at the 0.01 level. The dummy variable for federal regulatory efforts had positive coefficients in both cases but was insignificant. R-squared for these two time periods 1940 to 1965 and 1945 to 1965 were 0.73 and 0.52, respectively. For the nonfatal injury rates, the technology variable again was significant with a negative relationship to injury rates. In the one case in which mine size was significant, the sign was again negative. As with fatal injury rates, the federal regulation variable was insignificant with a positive sign. The percentages of variance explained were improved over those for fatal rates, with an R-squared of 0.93 for 1940 to 1965 and an R-squared of 0.91 for 1945 to 1965. The results for the nonfatal permanent disability rates were inconsistent between the two time periods 1940 to 1965 and 1945 to 1965. In the former time period, the technology variable and the size of mine variable (average output per mine) were significant and negatively related to injury rates (R-squared=0.85). The federal regulation dummy variable had a positive coefficient but was insignificant. In the latter time period, the technology variable had a positive coefficient as did the mine size variable (measured as average number of men working per mine). The federal regulation dummy variable was significant with a negative coefficient. This model was the only one which showed the expected sign (negative) for the federal regulation dummy variable and which was significant. Thus, this final model was unusual in more ways than one, as Andrews and Christenson point out by calling it a "maverick equation". Other models were presented in this paper for the time periods 1940 to 1952 and 1953 to 1965 but these results are not reviewed here since the federal regulation variable is not included in the models and, in general, the technology and size of mine variables behave similarly to the results given for the combined periods.

Federal regulation, in general, failed to prove a statistically significant variable in reducing injury rates in Andrews and Christenson's models. The authors rationalize these results with several possible explanations: (1) failure of the regression analysis to detect the true relationship, (2) the narrow scope of the 1952 legislation, in that it was designed mainly to prevent disasters which account for only a small portion of total injuries and also in that it excluded mines employing less than 15 persons underground and (3) a lack of enforcement power and a lack of cooperation and support for the law.

Palomba, et al. (1975) extended the Andrews and Christenson models to include the effects of the Federal Coal Mine Safety Act Amendments of 1965 and the Federal Coal Mine Health and Safety Act of 1969. Since the data they used were only for years through 1970, there was only one year in which the 1969 act was effective, probably not a very good way to capture any effects of this legislation. Updating of the models to 1970 led to a reduction in the explanatory power of the models, especially for the fatality rate and the nonfatal permanent disability rate. The dummy variable representing the 1965 amendments was significant in all models in which it appeared but had a positive coefficient falling between 0.2 and 3.7. The dummy variable representing the 1969 legislation was significant in only one out of six models; however, it had a positive sign in all models with a value falling between 0.08 and 2.9. Stating that these results are difficult to rationalize in the same manner in which Andrews and Christenson rationalized their results, the authors questioned the accuracy of specification of the model. It is possible the dummy variable is "capturing" factors other than safety legislation which may have increased injury rates. Certainly the model is not comprehensive enough; for instance, there are no independent variables representing geologic conditions or characteristics of the work force which affect injury rates.

In a later paper, Christenson and Andrews (1974) state that seam thickness could not be included in their multiple regression analysis since suitable data were not available. In this study they investigate the effects of seam thickness on injury rates and productivity. No conclusions are drawn concerning the effects of the mine safety law of 1952 on injury rates. The data are divided into two periods 1948 to 1952 and 1953 to 1965 representing times before and after the law was in effect. However, since many changes were occurring that could affect injury rates and that are not accounted for in their analysis, it would be incorrect to attempt to draw any conclusions as to the effects of regulation.

The relationship between fatality rates and seam thickness is generally an inverse one except for the thickest seams where the fatality rate increases. For nonfatal injury rates per million man-hours, the tendency is again for decreasing injury rates with increasing seam thickness. From their examination of data on labor productivity, the authors concluded that, in general, productivity increases with increasing seam thickness, falling off only as seams become greater than nine feet thick, or so. From these results, it seems apparent that a multivariate equation to explain either productivity or injury rates would benefit from the inclusion of seam thickness as an independent variable.

Witt, et al. (1974) developed a model to attempt to explain man-days lost in underground bituminous coal mining during the period from 1953 to 1969. This model is used to forecast the number of man-days that would have been lost in 1970, 1971, 1972 and 1973 in the absence of new federal legislation. To obtain an estimate of the benefits of the 1969 legislation, these predicted values were compared to actual man-days lost in these years. The econometric models were linear and log-log forms. The two dependent variables examined were the total number of man-days lost annually in fatal and nonfatal accidents and the total man-days lost minus man-days lost as a result of fatalities in disasters. The independent variables were meant to measure labor services, capacity utilization, neutral technological change and the Federal Coal Mine Safety Act Amendments of 1965. The variable measuring labor services was the number of man-days worked in underground bituminous coal mines. As indirect measurements of capital services (and the technological changes embodied in them), the percentage of coal mined by continuous miners and the percentage of coal loaded by mechanical loading machines were used. To measure "neutral technological change", they used a value of two in 1953 and incremental values of one each year thereafter. This variable is supposed to represent "those changes in organization and safety practices over time which were not embodied in either capital or labor" (p. 7). They also expect it to account for better job training and some improvements in capital equipment. The use of such a sequence of equidistant values is, however, statistically incorrect unless there is a good a priori reason for such a sequence (Kmenta, 1971, p. 412-413; Neter and Wasserman, 1974, p. 319). The use of such a sequence implies that the changes from 1954 to 1955 in "neutral technological change" were of the same magnitude as the changes from 1968 to 1969, for example (taking the value of one in both cases). Presumably, the authors chose these spacings arbitrarily probably based only on a time trend. The safety legislation was represented by a binary dummy variable taking the values zero and one. This indicator variable, in contrast, makes no assumptions about the spacing, relying only on the data to show the differential effects that occurred (Neter and Wasserman, 1974, p. 319).

The results of the regressions were best for the linear models rather than the log-log models in both cases; furthermore, elimination of disaster fatalities improved the results considerably by increasing R-squared and significance of variables. In the linear model including man-days lost from disaster fatalities, man-days worked was the only significant variable. In the linear model excluding man-days lost from disaster fatalities, man-days worked, percentage of coal mined by continuous miners and percentage of coal loaded mechanically were all significant. Neutral technological change and the dummy variable for the safety legislation had negative signs but were insignificant in both models.

Comparison of predicted man-days lost to actual man-days lost in 1970 through 1973 led the authors to estimate that federal legislation reduced the number of man-days lost by between 22 to 33 per cent when disaster fatalities are included and by between 14 to 24 per cent in the case excluding disaster fatalities. Of course, this assumes a continuation of past trends for the independent variables in the model, unaffected by the new legislation. They conclude that "federal legislation has had a substantial effect in reducing human capital losses in underground bituminous coal mining" (p. 11).

Neumann and Nelson (1976) have worked on a model to explain the total number of fatal plus nonfatal accidents in underground coal mines for the years 1950 to 1970. The basic model is (p. 29):

$$\begin{aligned} \ln A = b_0 &+ b_1 \ln \text{OUTPUT} + b_2 \ln \text{MFGWAGE} + b_3 \ln \text{CAPITAL} \\ &+ b_4 \ln (F/A) + b_5 \ln (\text{AMDL})_{-1} + b_6 \text{TIME} + b_7 \ln \text{SMALL} \\ &+ b_8 \text{DUMMY} + \mu \end{aligned}$$

where

A = total fatal plus nonfatal injuries in underground coal mining per year,

OUTPUT = coal production in underground mines in thousands of tons per year,

MFGWAGE = average hourly earnings in dollars per hour, adjusted for overtime in manufacturing industries,

CAPITAL = per cent of coal mined by continuous miners, in percentage points per year,

F/A_{-1} = total fatalities divided by total injuries in underground coal mining, in fractional experience per year, lagged one period,

AMDL_{-1} = expected man-days lost per nonfatal injury, expressed as man-days lost per nonfatal injury per year, lagged one period, TIME = 1950 = 1, 1951 = 2, ...1970 = 21,

SMALL = percentage of underground output produced in mines with less than 50,000 tons of output, in percentage points per year,

DUMMY = variable representing federal safety law of 1965;
DUMMY = 1.0 for 1966, 1967, 1968, 1969, 1970
DUMMY = 0 otherwise, and

μ = disturbance term.

They obtained results for the model as given and also excluding the variables DUMMY and SMALL one at a time. When both are included, the significant variables are OUTPUT, MFGWAGE, CAPITAL, TIME and SMALL (R-squared = 0.996). If SMALL is omitted, DUMMY AND AMDL_{-1} become significant. If DUMMY is omitted, the same variables are significant as when both DUMMY and SMALL are included. In both cases including the dummy variable, the sign was, as expected, negative. The authors used the model excluding the dummy variable to predict the total number of accidents in 1971 and 1972 to see whether any structural change had occurred causing the model to predict poorly these values. A pronounced change in structure was apparent, but the indication was that in 1971 and 1972 there were 16.2 and 7.8 per cent more accidents than were forcast by the model. These results seem to indicate the act caused more accidents, according to the authors. They are, however, skeptical about these results and suggest they could be due in part to an increase in the frequency of accident reporting by companies.

Neumann and Nelson justify including 1970 data in their estimation of the model by assuming the act was not fully enforced until late 1970. However, it seems probable that structural effects were, in fact, being felt in 1970 since the act had been passed and at least partially enforced.

Neumann and Nelson (1976) also developed a model for the level of labor demand expressed in man-days worked for a firm whose joint outputs are a primary product and safety. The model is:

$$\ln L = C_0 + C_1 \ln \text{OUTPUT} + C_2 \ln \text{MFGWAGE} + C_3 \ln \text{CAPITAL} + C_4 \ln (F/A)_{-1} + C_5 \ln (\text{AMDL})_{-1} + C_6\,\text{TIME} + C_7 \ln \text{SMALL} + \mu$$

where

L = total employment in underground mining, in average number of men employed per year

and the other variables are as defined in the previous discussion. Estimation is again performed on annual data for the years 1950 to 1970. The results of the regression indicate that OUTPUT, MFGWAGE, CAPITAL, $(F/A)_{-1}$, TIME and SMALL are significant (R-squared = 0.998). Again, the model was used to predict labor demand in 1971 and 1972, with the expectation being that the model should underpredict if the 1969 act caused a structural change or decreased productivity. A comparison of actual to predicted values for labor demand in man-days worked showed an underprediction in 1971, as expected, but an overprediction in 1972. The authors suggest this supports the "hypothesis" that "the productivity effects of the Coal Mine Health and Safety Act of 1969 were of a one shot nature, and not cumulative" (p. 37). However, evidence to the contrary seems overwhelming as productivity has continued to show a strong downward trend since the 1969 legislation was passed.

There are many factors that affect a mine's productivity other than federal regulation. The identity of these factors must be known to develop a meaningful multivariate model of productivity. Malhotra (1975) has discussed a number of factors which influence underground mines productivity and has suggested other factors which could not be analyzed due to a lack of data. At this point, these factors will simply be enumerated and major conclusions will be given. The factors include: (1) seam thickness, (2) roof and floor conditions, (3) size of the operation (annual production capacity), (4) age of the operation, (5) effective use of mining equipment, (6) quality of the finished product (coal preparation), (7) presence of water in the mine, (8) quantity of methane emitted and (9) management attitudes. The major conclusions he reaches are as follows:

(1) A definite gain is experienced in productivity as seam thickness increases. This gain levels off when the coal reaches about six feet.

(2) Roof and floor conditions are of great importance in determining the productivity a mine could achieve. In a year's time, a loss of between ten and 35 per cent is possible with a bad roof in a mine.

(3) Productivity increases with increasing annual output of a mine but levels off at around two to three million tons per year.

(4) Mine productivity and the age of an operation are negatively correlated after the initial five to seven years of operation. During the initial years of operation the correlation is positive.

(5) Regarding the efficiency of equipment and time use, an increase in output to over 450 tons of coal per mining unit per shift increases productivity.

(6) The degree of preparation the coal receives before it is shipped has a negative correlation with productivity, as would be expected.

Research in the area of quantifying the benefits and costs of the 1969 legislation in actual dollar terms has been limited. Witt, et al. (1974) have done preliminary work in this area. Moore (1973) has done work on costing of human capital, although it was not for the purpose of measuring the benefits of the 1969 act. Stilley (1975) has analyzed the costs of accidents in coal mining. These studies are discussed here as they apply to the present work.

Witt, et al. (1974) discuss briefly the costs incurred by the mining industry because of the Coal Mine Health and Safety Act of 1969. They assume a preliminary figure of $1.50 per ton of coal as the cost for the period 1969 through 1972 and indicate they believe this to be a high estimate. This figure of $1.50 is based on the work of John W. Straton (1972) in three surveys of the coal mining industry, each survey more comprehensive than its predecessor. The first survey which covered the time period 1969 to March, 1971 indicated that tons per man were reduced by 21 per cent and tons per unit shift were reduced by 22 per cent as a result of the 1969 act. The second survey for the time period 1969 through September, 1971 indicated that the number of tons per man decreased by 26 per cent with continuous mining and by 32 per cent with conventional mining. The reductions for tons per unit shift were 21 per cent and 28 per cent, respectively. The corresponding average cost increase was $1.50 per ton. The third survey, which covered more mines than the other two, supported this cost figure. The decreases in tons per man were 22 per cent for continuous mining and 31 per cent for conventional mining; the corresponding decreases for tons per unit shift were 19 per cent and 26 per cent, respectively. The average cost figure in this study was $1.47 per ton.

Using Straton's figure, Witt, et al. (1974) calculate the total production cost of the 1969 act to be approximately $414 million in 1971, $456 million in 1972 and $450 million in 1973. The resources expended to administer the act are another element of cost. From 1968 to 1972 the number of coal mine inspectors and engineers employed by the Bureau of Mines increased by 1,256. Using 1958 data on wage levels of mine inspectors and updating to 1972, they estimate an average salary of $18,000 in 1972. They calculate the cost of additional personnel to be approximately $68 million for three years (1971 through 1973). This figure added to the production cost gives a cost of about $463 million per year for the 1971 through 1973 period. For the portion attributable to the safety (not the health) regulations, the authors arbitrarily halve the above figure to get $231 million.

The above analysis could be improved by a more detailed study of costs. For example, additional capital equipment costs should be evaluated.

Witt, *et al*. (1974) also have made preliminary estimates of the actual economic benefits of the 1969 safety law. They used the principle of costing human capital loss by lost wages. They had made an analysis of the number of man-days saved by the 1969 legislation as discussed previously in this section. These data involved fatalities, permanent injuries and temporary injuries. They required an estimate of the length of time over which the economic value of the human capital services saved would accrue. The assumptions made were: (1) the man-days lost due to temporary injuries were all in the same year as the injury, (2) 20 per cent of the total days lost in the period 1971 through 1973 were from temporary injuries[1] and (3) the period of time over which the permanent and fatal injuries would accrue was 27 years[2].

A daily wage rate of $39 in 1971 was derived using data from the Bureau of Labor Statistics on all coal miners' wages. This figure agrees with that derived by taking the midpoint of the range of standard daily wage rates for underground miners in the 1971 collective bargaining agreement. These collective bargaining agreement data yielded average daily wage rates of $43 for 1972 and $46 for 1973. In order to estimate wages lost in the future due to accidents, they required an increase factor reflecting the future expected wage increases. The authors chose a range for mining wage increases of six per cent to eight per cent based on Bureau of Labor Statistics data and collective bargaining data. The former source showed that a growth rate of four per cent per year applied to the time period 1960 through 1971 and a growth rate of six per cent per year applied to the period 1966 through 1971. The latter source indicated an average increase factor of eight per cent from 1971 to 1972 and seven per cent from 1972 to 1973. The discount rate they selected as appropriate for their benefit analysis was ten per cent.

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[1] This figure was derived by inspection of data for the years 1965 through 1971.

[2] This figure was derived by dividing 6,000 days (the days lost charged to a fatality by the Bureau of Mines) by 220 days per year (the average days worked in a year).

The above data were combined with their estimates of man-days saved by the 1969 act for the period 1971 through 1973 in the following manner. Twenty per cent of the man-days saved (the temporary injuries) were multiplied by the daily wage rate figure appropriate for the year in which the injuries were saved (no increase factor or discount rate needed). The nontemporary component of man-days saved required the use of a discount rate and an increase factor (six per cent, seven per cent and eight per cent). Of course, the lower increase factor for wages resulted in the lowest estimate of benefits and the higher increase factor resulted in the highest estimate of economic benefits. Furthermore, different results were obtained depending upon which of their two econometric models was used to determine man-days lost, either including or excluding fatalities from disasters. For the 1971 to 1973 period an average per year figure for benefits using the model excluding disaster fatalities and an increase factor of seven per cent was approximately

$10 million. The corresponding figure for the model including disaster fatalities was approximately $16 million.

Witt, et al. (1974) also discussed the quantification of potential economic benefits of the legislation. The approach was to put a value on the actual number of work days lost due to accidental injuries in the period 1971 through 1973 using the method of analysis just described. The rationale was that this figure would represent the benefits of eliminating all fatalities and nonfatal injuries in underground coal mining. Obviously this is practically impossible, however, the figure derived is instructcive. Witt, et. al. determined that the measurable economic benefits using an increase factor of seven per cent would be an average of about $40 million per year for the period 1971 to 1973 (p. 17). Comparing this figure to the cost figure they derived for the same period, $231 million (for safety but not health), they concluded that even the potential economic benefits fall short of the costs for safety alone.

Witt, et al. (1974) mention a possible area of economic benefits that might accrue if legislation reduced injury rates sufficiently. That is, days lost due to work stoppages associated with working conditions might decrease. Other benefits should be measured to complete the analysis, as the authors mention. For instance, additional social benefits of the act include the reduction in care and rehabilitation costs associated with injuries.

Moore (1973) has presented a study which involves costing of death and injury in underground coal mines. This was not for the purpose of measuring the particular benefits of the Coal Mine Health and Safety Act of 1969; however, the methods he employed are reviewed since they could be applied to this purpose. He has used four human capital models, all based on the assumption that the costs of an accident can be derived as loss of earnings. The four variations are: (1) a model based on discounting wages in the mining industry, with no allowance made for consumption expenditures of the individual killed; (2) a model based on discounting wages which are taken to be based on average hourly earnings in mining, as in (1), but with an allowance made for the consumption expenditures of the individual; (3) a model based on discounting wages which are taken to be based on average hourly earnings in all manufacturing with no allowance made for the consumption expenditures of the individual; and (4) a model like (3) except it is net of consumption allowances. The accident data used were fatalities and nonfatal injuries for selected years. The results were presented for models (1) and (4) using discount rates of five per cent and eight per cent, respectively. There is no mention of the value assumed for the wage increase factor. The greater accident costs result from model (1). To these costs Moore added the costs he estimated to be associated with disease. Since this work is very preliminary it will not be discussed at this point. The problems of estimating the costs of black lung disease were analyzed by Robert B. Cameron (1976) in a thesis study which was a part of the NSF/RANN project for which John R. Moore was the principal investigator. This study will be discussed in another section dealing with the quantifying of the benefits of the health provisions of the legislation.

Stilley (1975) made quantitative estimates of the tangible costs of accidents in coal mining in 1971. He also used the principle of lost wages; however, he made several adjustments to the basic expected future earnings model. For both nonfatal and fatal injuries, he deducted from the income lost figure the portion of income that would have been paid as taxes (12 per cent of the income) and added the value of "lost services which the injured miner cannot now provide for his family, which either must now be purchased or gone without" (p. 65). He uses the figure of 8.5 per cent for this latter factor although he does not justify this choice. I question the use of this "lost services" measurement, especially at so high a percentage of the miner's income. Some examples of the types of services the author had in mind would have been useful. The adjustments to the expected earnings model were made so that the results would reflect the cost of accidents to the miners and their families.

The calculation of the value of income lost to fatally injured miners and their families involves the same procedure as for nonfatal injuries with two additional adjustments. These are an 8.5 per cent loss to survivors in the form of retirement benefits and a 25 per cent credit for the fraction of the future expected earnings that the worker would have consumed if he had lived. These percentages are applied to the total future projected earnings. For all calculations he assumed that the wage increase factor and the discount rate were both five per cent.

To adjust the figures he derived as costs to individuals of accidents, he subtracted the portion subsidized by compensation, taken to be two-thirds of the total cost.

Stilley (1975) states that the costs imposed on industry by accidents include lost production, compensation payments, medical expenses, recruiting and retraining and damaged public image. The method used for computation of lost output seems somewhat strange, as he seems to be assuming that no one is taking the job vacated by an injured or deceased miner. Obviously, since a unit consists of a certain number of men required for efficient operation, the loss of one man will result in the placement of another unemployed miner or a new recruit in his place. To supposedly derive the loss in production, the author took the total number of man-days worked in 1971 (31,527,000) and added to this figure the total number of man-days lost in 1971 (1,677,760) to derive what he calls the total number of man-days which would have been worked in 1971 had there been no accidents (33,204,760). Using this figure plus the value of coal produced in 1971 and labor's role in production as a percentage of the value of the coal, he attempted to derive the value of foregone production resulting from injuries in coal mining in 1971. Undoubtedly, there is some loss of production associated with accidents; however, this method is probably not the best way of quantifying these costs.

To calculate the cost to industry of workmen's compensation and medical expenses, Stilley multiplied the premium rate by the total wages and by the per cent of claims that are due to injury disability (50 per cent).

The cost of recruiting and training of men to fill the jobs of fatally or permanently injured miners was derived by multiplying the cost of training one man by the number of men killed or permanently disabled in 1971. The estimate for training costs, offered by a coal company executive based on his company's experience, was given as $121 per trainee for a three day training period including wages.

Stilley added what he calls public costs of accidents in lost tax revenues, further "hidden costs" to the industry (see p. 27-29) and indirect costs due to work stoppages over unsafe conditions.

Concerning costs of prevention of accidents he calculated the costs of lost production similarly to Witt, et al. (1974) and included costs of expenditures on the 1969 act. For 1971 data, he concluded that the cost burden of actual accidents that occurred exceeds the expenditures made on their prevention. This is, of course, not the same as a benefit-cost analysis of the 1969 act which theoretically should compare the costs of accident prevention (and health improvements) to the benefits derived from the act in such things as lowered injuries and health improvements.

In summary, several models and methods have been presented which have been used by various investigators to try to quantify the savings in human capital or losses in productivity (and other costs) due to the 1969 legislation. The methods for putting dollar figures on saving life and limb which have been discussed mainly use the idea of costing accidents by discounting the future expected earnings of the injured.

Factors Affecting Productivity

Summary of Factors Affecting Levels of Productivity

The measurable variables affecting productivity in underground mines may be classified under two broad headings:

1. Internal
    a. Geologic conditions associated with the operation including seam thickness, roof and floor conditions, presence of water, and gassiness
    b. Technology employed in the mine including types of machinery used and methods of production
    c. Scale of operation
    d. Regularity of operation
    e. Age of operation
    f. Characteristics of the work force including experience level, training, attitudes, and wildcat strikes
    g. Management factors such as expertise of personnel and attention to planning
2. External
    a. Price of coal
    b. Federal and state controls

The effects of these factors are discussed in this section.

Geologic Conditions

Risser (1966), Shields et al. (1954), and Malhotra (1975) have demonstrated that increases in seam thickness result in higher productivity. An obvious cause for this increase in productivity is the fact that as the seam thickness increases there is a greater amount of coal available in a given area. Furthermore, machine maneuverability is improved by thick seams, thereby improving the efficiency of mining. This positive relation of productivity and seam thickness does not extend, however, to extremely thick seams. Shields et al. (1954) and Malhotra (1975) have shown that productivity increases significantly up to about seven feet and then tends to level off for thicker seams. Christenson and Andrews (1974) show an increase in productivity with seam thickness up to nine feet and a decrease in productivity with thicker seams. Given (1973) states that productivity is reduced for very thick seams by increased difficulties of mining.

Poor roof conditions increase the amount of labor devoted to roof bolting, adding timber and cribs for support, recovering and repairing equipment buried by roof falls, and removing fallen rock. Labor expended for these purposes, of course, lowers the productivity. Roof conditions are related to the geological and physical characteristics of the overlying strata, particularly the 20 to 30 feet of rock directly above the coal seam. The characteristics of the overlying strata may vary considerably from one mine to another and even within a single mine (Malhotra, 1975, p. 3). Hence, roof conditions may also vary widely.

In mines where floor upheaval is a problem much labor must be spent on grading floors, thereby reducing productivity. The problems caused by floor upheaval and poor roof conditions have forced abandonment of mine sections and have made continued operation of a whole mine uneconomical (Malhotra, 1975, p. 3). If water is present, this will be an additional production handicap.

The general roof and floor conditions of coal mines in a state (as would be expressed by a weighted average) may have changed notably during the period covered by this study. These conditions might have a significant effect on productivity. The "best" mines probably were developed before opening places with less desirable physical conditions and more difficult engineering problems. Malhotra (1975, p. 3) states that in Illinois, mine operators estimate that 10.0 [illegible] 35.0 percent of productivity could be lost in a given year due to poor roof or floor conditions. However, it is also possible that in a specific state the "average" roof and floor conditions have not changed substantially from year to year, especially if the same coal seams are being mined. Unfortunately, these conditions are not easily quantified, and measurements of them are not available.

Technology

Theoretically, the conventional mining and continuous mining methods can achieve similar output levels. However, the crew for conventional mining consists of 12 to 14 workers, whereas the crew for continuous miners consists of only seven to nine workers. Therefore, productivity is expected to be higher in operations employing continuous miners than in those using the conventional method and to increase as the percent of output mined by continuous miners increases. Productivity is improved by machine loading.

Scale of Operation

Productivity is affected by the mine size or level of output. If an increase in output is desired in a mine using continuous miners at full capacity, that is, three eight-hour shifts per day, any substantial increase in output requires adding continuous miners. This will increase the number of men employed on the machines (seven to nine men on a continuous miner unit), but supervisory, maintenance, and other required personnel will not necessarily increase proportionately to the number of units added. Hence, a gain in productivity as measured by output per man-day can be achieved. Malhotra (1975) shows that for Illinois mines, an increase in the level of output brings a decrease in the number of additional workers required up to output levels of two to three million tons per year and then levels off. This leveling off could be due to bottlenecks in transporting coal from the mine.

Regularity of Operation

Productivity is also affected by the regularity of operation. If miners work irregularly, they may be less efficient in performing their jobs. This is because they lose their "sharpness" built up by habit or repetition. Furthermore, mines tend to deteriorate when inactive. Water may build up, roof may collapse, and equipment may deteriorate. When the mine reopens, cleanup and repairs are likely to require more time than preventive and scheduled maintenance.

Age of Operation

Another factor affecting productivity in underground coal mining is the age of the operation. In general as mining proceeds, miners must be transported farther to reach the working face and coal must be hauled greater distances. If old or obsolete equipment is not replaced efficiency will decrease. Malhotra (1975, p. 6-7) demonstrates that in Illinois productivity tends to increase during the first seven years of operation of a mine and that after ten years of operation productivity gradually declines, regardless of the level of production. He concludes that the relatively high productivity in the first seven years of operation "reflects the general mining principle of first mining the areas easiest to reach to get a quick return on the capital investment" (p. 7). Again, unfortunately, these data are not available for all years in all states.

Characteristics of Work Force

Some other factors affecting productivity are the experience level of of the work force and labor unrest. Inexperienced miners tend to be less efficient than those with experience. Labor unrest may result in miners performing their duties at a slower pace or lead to wildcat strikes which in turn may affect the regularity of operation of the mines. At the time of the preparation of this study, no data on these factors were available.

Regulation

The Coal Mine Health and Safety Act of 1969 is expected to have an adverse effect on productivity. Because of the Act more time must be spent on activities that do not produce coal. For example, more roof bolting may be required, a greater degree of rock dusting must be undertaken, and electrical wiring must be kept more free of coal dust than would otherwise be done.

Management Factors

The competence of management is of great importance in the modern coal mine. Movement of equipment and men is complicated. Delays may be avoided and full utilization of equipment may be achieved only by careful planning regarding such operations as haulage and roof bolting. These factors do not lend themselves to quantitative analysis, however.

Price of Coal

The market price of coal affects productivity in the following manner. If the price of coal rises, mining will be done in areas with less favorable conditions overall than those mined at lower prices. Furthermore, mines with lower expected productivity might be opened and developed when prices and anticipated future prices are high. Another possible reaction to rising price is that percentage recovery of coal will increase where possible, even though the marginal production is achieved at lower levels of productivity. Thus, the expected relationship between price and productivity is negative.

Econometric Model of Productivity and Variables

Econometric Model

The general model to be studied is:

$$PRY = f(S, G, T, O, P, R)$$

where PRY is productivity in terms of tons per man-day, S is a mine-size variable, G is a variable for geologic conditions, T is a technology variable, O is a variable for regularity of operation, P is a variable for price of coal, and R is federal regulatory activity. The model does not include management factors or age of operation as no data were available. Data on wildcat strikes were available for only ten years, 1965 through 1974 (U.S. Bureau of Labor Statistics computer data tape supplied by Arthur D. Little, Inc.) The regressions were run for each state with a variable for wildcat strikes (WCT), defined as:

$$WCT_t = \frac{\text{number of man-days lost in wildcat strikes in year t}}{\text{total number of man-days worked in year t}}$$

The results showed this variable to be insignificant, in general, with positive signs in most cases. Data on age of workers were available by state for only one year, 1976 (Brophy Associates, 1977).

The model for productivity is:

$$PRY_t = a_o + a_1 AP_t + a_2 ST_t + a_3 CM_t + a_4 DO_t$$
$$+ a_5 PR_t + a_6 MACT_t + e_t$$

where PRY_t = productivity in tons per man-day in year t,

AP_t = average production in millions of short tons in year t,

ST_t = weighted-average seam thickness in year t,

CM_t = percent of coal mined by continuous miners in year t,

DO_t = weighted-average days in operation in year t,

PR_t = price of coal in year t, adjusted to exclude effects of CMHSA,

$MACT_t$ = variable to represent Mine Act in year t,

e_t = error term, and a_o is a constant and a_1, a_2, a_3, a_4, a_5, and a_6 are regression coefficients. The dependent and independent variables are discussed in detail in the next section.

Dependent and Independent Variables and Data Sources

The dependent variable is defined as follows:

$$PRY_t = \frac{\sum_{i=1}^{n} PROD_i}{\sum_{i=1}^{n} MD_i}$$

where $PROD_i$ = the annual production at mine i in year t, in short tons

MD_i = the number of man-days worked at mine i in year t, and

n = number of mines in the state sample in year t.

The variable for mine size is average production (AP) defined as:

$$AP_t = \frac{\sum_{i=1}^{n} PROD_i}{n} \times 10^{-6} \quad ;$$

that is, the average production per mine in millions of tons in year t.

The variable representing physical characteristics of the mine is average seam thickness weighted by production (ST). The formula used to calculate these values from individual mine data is:

$$ST_t = \frac{\sum_{i=1}^{n} (ST_i \times PROD_i)}{\sum_{i=1}^{n} PROD_i}$$

The actual physical average of the thickness of all mined seams would have little meaning in this study. It was decided to weight the seam thickness by production so that the seam thickness at a mine with large production would "count" for more than one with small production. The variable is, therefore, weighted by production so that the average annual production can be thought to be mined from the calculated "average seam thickness" for a given year.

The technology variable is percent of coal mined by continuous miners in year t (CM_t). This variable was chosen over percent of coal loaded mechanically to represent technological changes impacting on productivity in the industry. The introduction and increased use of continuous miners is generally given major credit for the rapid gains in productivities achieved since the late 1940s.

Accounting for regularity of operation is weighted-average days in operation, defined as:

$$DO_t = \frac{\sum_{i=1}^{n} (DAYS_i \times PROD_i)}{\sum_{i=1}^{n} PROD_i}$$

where $DAYS_i$ = number of days in operation at mine i in year t.

The weights were applied for the same reason given for seam thickness.

The price of coal as used in this study is the annual "average" price of coal in 1975 dollars for each state. These prices have been adjusted in 1970 through 1975 so they will not reflect impacts of the CMHSA. If the price were not adjusted thusly, some of the negative effects of the Mine-Act variable would be taken up by the price variable. In other words, since a portion of the price increases in 1970 through 1975 was due to increased costs related solely to the regulation requirements, this portion should be removed to allow the Mine-Act variable to take on its full negative impact on productivity. Of course, it is this variable, MACT, which is of primary interest in this study. Prices were adjusted using results obtained by Fettig (1978, p. 53) on required selling prices of coal in five states with and without the Act. Percentage changes in prices were applied to actual prices to obtain adjusted values; these percentages are: 35.61 for Pennsylvania, 24.93 for West Virginia, 27.73 for eastern Kentucky, 30.11 for Ohio, and 42.56 for Virginia.

The variable for the 1969 Act ($MACT_t$) is designed to reflect to some degree the extent of regulatory activity as related to the number of federal inspections made. This expression of the degree of enforcement of the Act should be more powerful in explaining its impact on productivity than would be its mere existence, as would be expressed by a dummy variable. $MACT_t$ takes the value of zero for the years 1950 through 1969 in which no inspections under CMHSA were conducted. For the years 1970 through 1975, the value of

$MACT_t$ is calculated as:

$$MACT_t = \frac{\text{number of federal underground inspections in year t}}{\text{number of mines in year t}}$$

No data were available on the number of inspections by state; only data for the whole United States were available.

Factors Affecting Injury Rates

Summary of Factors Affecting Levels of Safety

The variables affecting safety in underground mines may be classified under three broad headings (Andrews and Christenson, 1974, p. 365):

1. Internal
    a. Physical environment of the mine including extent and depth of the workings, seam thickness, gassiness, presence of water, faulting, and nature of the overlying and underlying strata
    b. Technology employed in the mine including methods of production, types of machinery, state of maintenance of equipment, ventilation system, lighting, and rescue equipment
    c. Scale of the operation including the volume of output, number of employees, and number of units
    d. Ownership of the operation whether a captive or independent mine
    e. Characteristics of the work force in the mine including their age, experience, training, attitudes, and perhaps degree of unionization
    f. Management factors such as the emphasis on safety practices and the number of management personnel
2. External
    a. Federal and state controls
    b. Public opinion as to mine policies and operations

3. Random

   This includes chance elements of human error, equipment failure, or other unpredictable occurrences.

Most of these factors are subject to some degree of control. The probable exceptions are physical environment of the mine and random occurrences.

Physical Environment of the Mine

The physical environment of the underground mine is obviously an extremely important factor affecting injury rates. It is, of course, virtually impossible even with the best engineering to create the rigorously controlled environment possible in most manufacturing industries. The environment is, in fact, undergoing almost constant change, thereby making control even more difficult. A mine with poor roof conditions is likely to have higher injury rates from roof falls than a mine with good roof conditions, just as a gassy mine has a greater probability of an explosion than a mine which is not gassy, ceteris paribus. Of the important physical and geological characteristics mentioned, the one for which consistent and reliable data are presently available is seam thickness. Christenson and Andrews (1974) have reported on some relationships observed between injury rates and seam thickness. First, the definition of a disaster is an accident that results in the death of five or more men. This precludes the occurrence of disasters in very small operations. Furthermore, disasters tend to be associated with explosions or mine fires; these occur mainly in larger operations with thick seams where coal dust accumulations may be more extensive. In larger mines with thick seams, ventilation systems might be more complex and any breakdown more hazardous (Christenson and Andrews, 1974). Since seam thickness and mine size are correlated to some degree, this suggests that if the dependent variable fatality rates were defined to include those fatalities resulting from disasters, the relationship might be such that the coefficient of seam thickness would be expected to be positive. This would depend in part, of course, on the relative number of disaster fatalities as compared to all fatalities. On the other hand, if the fatality rate excludes deaths from disasters, the coefficient of seam thickness might be expected to be negative. One reason for this is that thicker seams should intuitively be expected to provide a setting in which operations could be safer. Part of this tendency for increasing safety with increasing thickness of coal seam might be credited to size of the firm, assuming larger firms tend to mine the thicker seams. Larger firms should, theoretically, be in a better position than small firms to implement effective safety programs because they have greater capital resources to draw upon and perhaps experience greater pressure from public opinion to do so.

Technology

The technology employed in a mine, both for production of coal and production of "safety", might affect the magnitude of the injury rates. There has been something of a small industrial revolution in underground coal mining in the past two decades. In general, injury rates per million tons of coal produced have tended to decrease over time due to technological advances and the enduced increase in productivity (output per man-day) experienced. Technology has, in fact, decreased the exposure of miners to risk, thus lowering the cost of injuries for a given amount of production. The individual miner, however, is concerned about the chance of injury during a given time period of work; injury risk in these terms is the accident rate expressed per million man-hours. Both of these rates are examined in this study.

The loading of coal mechanically rather than by hand has very likely been a positive factor in decreasing injury rates over time. Andrews and Christenson (1974) found this to be the case in a multiple regression study of injury rates. The impacts on safety of the introduction of continuous mining machines and other heavy equipment are a bit more difficult to assess. Some observers think continuous miners make mining more dangerous since they have extended high-voltage electrical lines to the working face. Others seem to feel that the increased danger, if any, applies mostly to the operator of the continuous mining machine. Another plausible hypothesis is that modern mining methods are as safe as, or safer than, older methods. Other important technical factors affecting safety in underground mines are the state of maintenance of equipment, lighting, ventilation, and rescue plans and equipment. Technological improvements in safe mining practices over time such as improved ventilation systems should tend to decrease accident rates.

Scale of Operation

The scale of operation theoretically could affect injury rates. Christenson and Andrews (1973) have reported statistics on injury rates by mine size. These data support the theory that mine size affects injury rates. The relationships they observed from these data are: (1) small mines (less than 15 employees per mine) are more dangerous in terms of fatalities than large mines, (2) small mines are less dangerous in terms of nonfatal accident rates per million man-hours worked, and (3) small mines are more dangerous in terms of nonfatal accident rates per million tons produced. Christenson and Andrews suggest the possibility that larger mines provide more complete reports on nonfatal injuries, making their rates appear higher than small mines. It also seems equally possible that larger mining operations find it easier than smaller operations to "hide" some of the nonfatal injuries. Certainly, there are serious difficulties in the measurements made of nonfatal accidents of a less serious nature. There is evidence that some companies actually do choose to provide an injured man with a less strenuous job of any kind rather than allow him to forfeit days worked at his normal activity. Such a case would not show up as a nonfatal injury resulting in days lost. Of course, nonfatal accidents resulting in permanent disability are probably reported nearly as accurately as are fatal accidents. Although the data seem to show a clear disadvantage to the small mine on fatality rates, this may not be entirely accurate. The apparently higher rates may be accounted for by the supposed failure of small mines to report fully and accurately on man-hours worked. Since fatalities are probably reported accurately, the rate in terms of man-hours would be overstated. Christenson and Andrews (1973, p. 73) further point out that "if this is true, and if nonfatal injuries are comparably reported by large and small mines; then the advantage of small mines on nonfatal injury rates per man-hour is greater than the published data suggest". However, their results in a later study using a multiple regression analysis of injury rates are of interest (Andrews and Christenson, 1974). They used technology, size of mine, a Federal regulation dummy variable, and a war dummy variable as independent variables to explain three injury rates in underground bituminous coal mines - fatal rates per million man-hours worked, nonfatal rates per million man-hours worked, and nonfatal, permanent disability rates per million man-hours. Several time periods were used producing a number of different models. The regression functions they chose were "selected from a larger number of fitted functions and represent the most favorable results for the different time periods and dependent variables" (p. 370). They found that increasing size of mine is associated with lower fatality rates (per million man-hours) for the time periods 1940-1952, 1940-1965, and 1945-1965. Size of mine coefficients for nonfatal accident rates are mainly negative with some exceptions. These exceptions match their earlier findings in which nonfatal rates showed some tendency to be higher for larger mines. For the nonfatal, permanent disability rate in the period

1953 through 1965 (the only case in which the equation for this time period is significant), size of mine is positively associated with the dependent variable. This relationship also holds in the 1945 to 1965 time period.

Some factors that might cause nonfatal injury rates to be greater in larger mines are: (1) the presence of more equipment and electrical lines, (2) congestion resulting from a greater number of people, (3) greater activity and movement of crews, and (4) more extensive use of highly mechanized techniques possibly raising the likelihood of serious injuries.

Ownership of the Operation

Captive coal mines[1] generally have better safety records than coal mines owned by coal companies. There allegedly has been emphasis on safety and training in these mines, and more money and energy have been invested in their safety programs (Conti, 1973). Captive mines were in a better position to comply with the new law in 1969 than were independent mines and experienced lower cost increases per ton due to the Act (Witt, et al., 1974, p. 12). Although this may be a factor in determining safety levels and thus injury rates, the data were not broken down in this manner to be used in this study.

Characteristics of the Work Force

Certain characteristics of the work force are very important factors affecting injury rates, and it is unfortunate that these data are not available for this study. Characteristics of importance are experience, training, age, attitudes, and perhaps degree of unionization of miners.

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[1] Captive mines are mines owned by utilities and steel companies. Their output is used mostly in the owner's electricity generating or steelmaking facilities.

Experience can be divided into two types: total mining experience and task experience or the experience of a worker with the particular task he was performing at the time of an injury. A study of 731 fatal accidents suggests a strong inverse relationship between total number of accidents and task experience (Barry and Associates, 1971). There is, in fact, an exceptional decline in the number of accidents as a function of increasing task experience. This holds not only for accidents related to equipment but also to roof fall accidents, usually assumed to be difficult to avoid. Although nonfatal accidents were not included in this study, it seems intuitively correct to expect the same safety learning curve effect as with fatal accidents.

Pre-employment training is of importance in reducing injury rates, at least for the first few months of a miner's employment (Bascomb Associates, 1975). The study by Bascomb Associates also implies that the difference in injury rates between trained and non-trained men decreases over a time period of two years. There is also evidence that increasing foreman training is associated with lowered accident rates (Reyes Associates, 1975).

There is general recognition of the fact that the age of a miner may be a factor in determining injury rates. This relationship was noted by the director of safety for a coal mining company. He pointed out that accident rates are higher for the below 25 years of age group, begin to decline somewhat at age 25, and finally level out around the age of 35. He attributed this to the introduction of family responsibilities in the older miners (personal interview).

Attitudes of miners toward safety responsibility is certainly of importance in determining injury rates, however, this factor does not lend itself to quantitative analysis.

The degree of unionization of the work force could be a factor in the levels of safety in mines. The United Mine Workers of America have provisions for safety requirements in their contracts that may go beyond requirements from other sources.

Management Factors

The emphasis placed on safety by management should be of some importance in determining injury rates. This was mentioned in regard to the superior safety records of captive mines. Since the mine foreman is in the best position to regulate and encourage safe practices by miners, he is most likely to place emphasis on safety if his employers expect this of him. The priority given by management to improving mine safety when translated into dollars spent on training and safety equipment is also of importance. This, too, would be difficult to analyze quantitatively unless some data were available concerning, say, expenditures on safety equipment per miner.

Federal and State Controls

Theoretically, the degree of state and federal regulation (and enforcement of regulations) of coal mine safety should affect injury rates. Since the purpose of the 1969 Act is to increase safety in mines in day-to-day operations, I expect there to be an inverse relationship between injury rates and the Act. On the other hand, there are observers of the industry who have noted that the detailed requirements of the Act result in the foremen of mines spending much of their daily work time insuring that the letter-of-the-law is met rather than overseeing the safe work practices of their crew. The implications of this for injury rates is unclear, however, since such a situation could have effects both of increasing and of decreasing injury frequency rates.

Public Opinion

Public opinion is also important in that it might be able to affect how much emphasis is placed on safety in a mine. On one level there is the obvious concern of people living in a mining community for the safety of the miners. On another level is the concern of society as a group for industrial safety and more efficient use of human resources. In the case of underground coal mining, public fervor is understandably at its peak after a major mine disaster and has triggered the passage of major federal legislation, including the Health and Safety Act of 1969.

Prices

On first thought, it might appear to the reader that price should also be included in the model for injury rates, since less productive areas that might be mined if price rises could also be more dangerous. However, this relationship between injury rates and price does not necessarily hold true. New areas may be more difficult to mine without having higher injury rates. One example would be going into an area where the coal has more partings of impure coal or clayey rock, leading to lower productivity but not higher injury rates. Another consideration is that an increase in the price of coal might allow increased expenditures on safety equipment and training of employees. Companies that were earning normal profits before the price increase would be earning rents with higher prices. A portion of these rents could be spent on equipment and training that would decrease injury rates in those mines. Thus, even if injury rates in some mines did increase due to the price rise, the overall effect on average injury rates would be indeterminate. There is also the possibility that mining in a new area and in changing conditions would engender more caution on the part of the workers than usual.

Econometric Model of Injury Rates and Variables

Econometric Model

The general model to be studied is:

$$I = f(P, T, S, R)$$

where I is the injury rate from accidental causes, P is a variable for mine physical characteristics, T is a technology variable, S is a size of mine variable, and R is federal regulatory activity. A weakness in the model is that there is no variable in the model reflecting characteristics of the work force. Unfortunately, no extensive time series data were available on these factors. There is also no variable in the model for ownership of the operation. It seems unlikely that there was a continued strong advantage for captive mines in terms of safety measures after other non-captive mines adapted requirements of the Act. Furthermore, complications might arise from the inclusion of this variable, since the percentage of total production by captive mines might be expected to increase because of the Act; however, the amount of this increase would be unknown. This increase in percent of coal mined by captive mines is expected because these mines had to make fewer changes to comply with the Act than non-captive mines, as mentioned before. Among the latter mines would be some that would close because they could not remain profitable under the new regulations, with the required cost increases per ton. This ownership variable would reflect part of the impact of the Act, and predictions would be affected.

The model for injury rates is:

$$\text{Injury rate}_t = b_o + b_1 ST_t + b_2 PMECH_t + b_3 MS_t + b_4 MACT_t + e_t$$

where Injury rate$_t$ = one of six different injury rates in year t,

ST_t = weighted average seam thickness in year t,

$PMECH_t$ = percent of coal loaded mechanically in year t,

MS_t = either average production in millions of short tons or weighted-average number of employees in year t,

$MACT_t$ = variable to represent Mine Act,

e_t = error term, and

b_o is a constant and b_1, b_2, b_3, and b_4 are regression coefficients. The dependent and independent variables will be discussed in detail in the next section.

Variables and Data Sources

The dependent variables studied are accident frequency rates rather than actual numbers of accidents. These were chosen to reflect changes in the risk factor to the miner. For example, production in short tons of coal might decrease over a time period, causing the number of accidents to decrease. However, unless the number of accidents per unit of production or per man-hour also decreases, there is no true decrease in accident frequency or in the risk the individual miner faces. The injury rates studied are the following:

1. $NFRMH = \frac{\text{Nonfatal injuries} \times 10^6}{\text{man-hours}}$
2. $NFRPR = \frac{\text{Nonfatal injuries} \times 10^6}{\text{production}}$
3. $FRMH = \frac{\text{All fatal injuries} \times 10^6}{\text{man-hours}}$
4. $FRPR = \frac{\text{All fatal injuries} \times 10^6}{\text{production}}$
5. $FRMHND = \frac{\text{Fatal injuries less disaster fatalities} \times 10^6}{\text{man-hours}}$
6. $FRPRND = \frac{\text{Fatal injuries less disaster fatalities} \times 10^6}{\text{production}}$

Originally, the possibility of studying the rates for total (fatal + nonfatal) injuries was considered by the author. The decision was not to consider such a rate for two major reasons. First, the rate would be extremely dominated by the nonfatal accidents since the number of nonfatal accidents greatly exceeds the number of fatal accidents per year. This would mean that the models for the total injury rates would be essentially repetitions of the models for the nonfatal injury rates. Secondly, a fatal accident is of a different class than a nonfatal accident, especially in the outcome and costs incurred. Thus, it would be inappropriate to add the two types of injuries.

The variables representing physical characteristics, ST, is discussed in the section on the productivity model.

The technology variable is the percent of coal loaded mechanically (PMECH). This variable was chosen over percent of coal mined by continuous miners to represent technological changes in the industry. First, there is little argument among persons knowledgeable about mine safety over the fact that mechanical loading of coal is safer than hand loading. On the other hand, there is disagreement among these observers as to whether or not continuous mining systems have affected safety and, if so, in what direction.

The mine-size variable is one of either:

1. $AEMPL_t$ = the average number of employees per mine weighted by the number of days worked in year t; that is

$$\frac{\sum_{i=1}^{n} (EM_i \cdot \frac{DAYS_i}{365})}{n}$$

where EM_i = the number of employees in mine i in year t

$DAYS_i$ = the number of days mine i operated in year t

n = number of shipping mines in year t, or

2. AP_t = the average production per mine in year t, in million tons

$$AP_t = \frac{\text{total production in year t}}{\text{number in year t}} \times 10^{-6}$$

The weights were applied to average employment to give a more meaningful measure of the "average" number of employees working to produce the average production in any given year. Again a straight average number of employees per mine would allow the same weight to be applied to a mine with 200 employees working only 100 days as to a mine with 200 employees working 300 days a year. The measure of weighted average employment is used as an independent variable in equations for injury rates per million tons produced, since the rates involve production. Average production is the mine size variable in equations for injury rates per million man-hours, since the rates being explained involve man-hours worked. The variable for the 1969 Act ($MACT_t$) is discussed in the previous section on the productivity model.

Data Sources

Data used for productivity, injuries, average production, seam thickness, average employment, days in operation, and percent mechanically loaded (for Illinois only) were obtained at the mine level from annual state mining reports where possible. Exceptions to these sources are specified as appropriate in the individual sections on state data analyses. For each state's annual data, all underground mines that produced at least 1,000 tons in that year were included in the sample, unless all necessary data were not reported for that mine. Data on percent of coal mined by continuous miners were obtained for each state from U.S. Bureau of Mines Minerals Yearbook for 1952 through 1975. Values in 1950 and 1951 had to be extrapolated; the percentage change from

1952 to 1953 was applied to obtain an estimate of values in 1950 and 1951. For example, if the 1952 value is 1.0 and the 1953 value is 1.3, the percentage change is 23.1 ($\frac{1.3-1.0}{1.3}$ X 100). Then the rounded-off values for 1950 and 1951 would be 0.6 and 0.8, respectively. Percent of coal mined mechanically was obtained from the same source, by state, for 1950 through 1975, except in Illinois for which data were obtained from state mining reports. Prices of coal were obtained for each state from the National Coal Association *Steam Electric Plant Factors* for 1951 through 1975 as tabulated for 1951 through 1971 in Gordon (1975, p. 30, 31, 38, and 39) and National Coal Association (1972 through 1975). Costs for 1950 had to be estimated. This was done by determining, for each state, the percent change in average value per ton from 1950 to 1951 as given in the *U.S. Bureau of Mines Minerals Yearbook* for 1951. These percentages were applied to 1951 costs to obtain estimates for 1950. All prices were inflated to 1975 dollars using the Gross National Product implicit price deflator.

Federal mine inspection data were obtained from the Mine Enforcement and Safety Administration (MESA) Information Office. These data are for underground mines in the entire United States; data by state were not available.

Methodology

Time series regression analyses are performed on data for each state from 1950 through 1975 where possible. Specific cases where data for all of these years are not available are explained in the appropriate results sections. The Econometric Software Package (ESP), version 01/01/76, is the computer program used for the regression analyses.

It would be inappropriate to use the technique of pooling cross-section and time-series data because the relationships between the independent variables CM and PMECH and the dependent variables PRY and injury rates, respectively, are expected to change over time. According to Pindyck and Rubinfeld (1976, p. 202), if cross-section parameters change over time, pooling is not an appropriate procedure. Relationship between the independent variables CM and PMECH and the dependent variables PRY and injury rates, respectively, change over time because the continuous miners and mechanical loaders of 1950 were improved upon over time. Thus, the magnitude of impacts of this equipment on the dependent variables would be different in 1960 than in 1950. The equipment parameters are the most obvious ones that are not constant over time; it is unclear whether the other parameters in the regressions would be constant or shift over time. However, it seems not unlikely that some might shift.

The trends of variables are examined, and piecewise regressions are made to determine statistical significance of changes in trend, with most interest focused on changes in 1969.

Results of regressions are presented with standard deviations of regression coefficients in parentheses below the coefficients. Significance levels based on t-statistics are indicated for 90.0 percent significance or greater, and 95.0 percent confidence intervals for coefficients are given. Coefficients of multiple determination, R^2, and standard errors of regressions are presented. For testing the hypothesis that all coefficients are simultaneously equal to zero, the F-statistic for each equation is given. Durbin-Watson statistics are given for each equation; this is used to test for the presence of autocorrelation of error terms. If the Durbin-Watson statistic

(D.W.) is inconclusive as to whether autocorrelation exists, the Hart-von Neumann statistic is used. The Hart-von Neumann statistic, which has no inconclusive region, is defined as (n-1)/n X D.W., where n is the number of observations. If autocorrelation is a problem in the ordinary least squares (OLS) regression, the Cochrane-Orcutt iterative technique (CORC) is used to attempt to correct the problem. Plots of residuals and actual and fitted values are presented. Plots of actual and fitted values make it possible to visually examine the goodness-of-fit. Residuals are examined for evidence of heteroskedasticity, non-constant variance of errors. Pairwise correlation matrices are presented for independent variables.

Predictions of productivity and injury rates in 1970 through 1975 assuming no CMHSA are made in the following manner. First, data through 1969 are used to obtain estimates of the multivariate model. Predictions are made using actual values of independent variables in 1970 through 1975. Secondly, predictions are made based on the results of the model for 1950 through 1975 by subtracting the influence of MACT on productivity and injury rates. Third, since productivity has such an "orderly" time trend, estimates are made by extrapolating time trends prior to 1969. This method gives predictions which may be considered to be maximum possible levels. Confidence intervals (95.0 percent) are constructed for all predictions, and these are compared to actual values.

CHAPTER III

RESULTS OF PRODUCTIVITY MODEL

In this chapter, analyses of state data and the results of regressions of the productivity model described in Chapter II are presented for West Virginia, Pennsylvania, Illinois, Ohio, eastern Kentucky, and western Kentucky. These regressions are made on data for 1950 through 1975 and on data for 1950 through 1969. Assuming there was no Coal Mine Health and Safety Act, predictions of productivity values are made for 1970 through 1975 using the estimated multivariate model. Predictions are also made using time trends. A third method used to make predictions is based on results of the model for 1950 through 1975; an estimate of the negative influence of the Mine-Act variable is subtracted from the prediction of productivity. All predictions are compared to actual rates.

West Virginia

Data and Trends of Variables

The data used for West Virginia are presented in Table 1. The state data on productivity (derived from figures on employment, days worked, and total production), average production, seam thickness, and days in operation were obtained from the West Virginia Department of Mines Annual Report for the years 1950 through 1975. Other data sources are as given in the section on methods of investigation.

The trend of productivity in West Virginia for the years 1950 through 1975 is shown in Figure 1. There was a steady increase in output per man-day from 1950 (6.21 tons per man-day) through 1967

Table 1

West Virginia Data

Year	Productivity PRY (tons per man-day)	Average Production AP[a] (tons)	Weighted-Average Seam Thickness ST (inches)	Percent of Coal Mined by Continuous Miners CM (percent)	Weighted-Average Days in Operation DO	Actual Price of Coal, 1975 Dollars PR_A (cents per million Btu)	Price of Coal Under the Assumption of No-Act, 1975 Dollars PR (cents per million Btu)	Number of Inspections Per Mine Under CMHSA MACT
1950	6.21	133044	60.58	0.6	191	42.4	42.4	0.0
1951	6.47	175655	60.15	0.8	226	39.3	39.3	0.0
1952	6.77	164309	59.54	1.0	206	40.1	40.1	0.0
1953	7.85	187187	59.86	1.3	206	38.7	38.7	0.0
1954	8.97	165173	61.11	2.4	204	37.7	37.7	0.0
1955	9.13	191800	60.51	4.9	233	35.7	35.7	0.0
1956	9.50	205780	61.86	8.0	227	35.2	35.2	0.0
1957	10.15	167526	61.40	11.9	223	35.8	35.8	0.0
1958	11.18	141054	61.00	17.1	201	35.8	35.8	0.0
1959	12.32	125178	62.13	23.8	203	36.0	36.0	0.0
1960	13.09	97418	61.06	28.9	206	35.0	35.0	0.0
1961	13.49	91429	61.33	33.6	210	33.8	33.8	0.0
1962	14.31	85620	60.36	35.2	209	32.8	32.8	0.0
1963	14.57	82639	60.88	38.7	225	31.8	31.8	0.0
1964	15.37	94633	61.59	44.2	230	30.8	30.8	0.0
1965	15.62	101484	61.15	47.4	232	30.3	30.3	0.0
1966	15.99	105899	61.64	50.3	228	29.5	29.5	0.0
1967	16.18	127386	62.04	52.0	233	30.1	30.1	0.0
1968	16.07	138974	62.62	52.0	228	29.6	29.6	0.0
1969	15.21	136835	62.70	55.4	218	29.6	29.6	0.0
1970	13.50	157946	63.34	54.7	230	34.1	27.3	5.15924
1971	10.74	145500	63.73	62.0	218	41.6	33.3	10.46780
1972	11.03	180209	62.98	64.2	229	44.4	35.5	29.23300
1973	10.70	183527	62.54	66.0	230	45.9	36.7	42.68330
1974	10.20	138503	62.83	68.5	201	86.7	69.4	52.09470
1975	8.58	123230	62.79	70.4	220	87.2	69.8	39.14790

[a] AP A note that when regressions were run, values shown here were divided by one million so that AP here and for other states is in millions of tons.

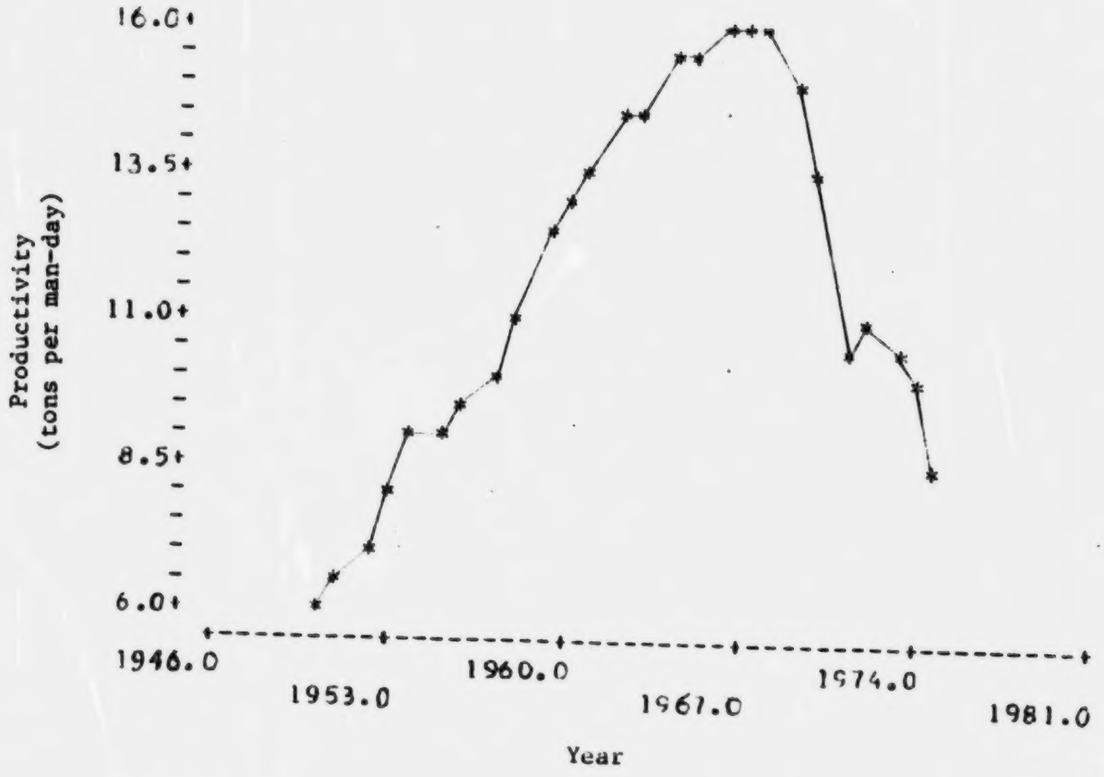


Figure 1 . Trend of Productivity in Underground Coal Mines: West Virginia (1950 Through 1975)

(16.18 tons per man-day) (Table 1); however, the percentage increase declined over this time period. In the years 1950 through 1955, the total increase in productivity was 47.0 percent; in 1955 through 1960, the percentage increase was 43.4; during 1960 through 1965, the percentage increase was only 19.3; and during the late 1960s (1965 through 1969), there was an overall decrease in productivity of 2.6 percent. In 1968, productivity began to decline, reaching 8.58 tons per man-day in 1975. Average productivity had not previously been that low since 1953. The overall decrease in productivity for the time period 1969 through 1975 was 43.6 percent.

Using piecewise regression, it was found that the change in the trend of productivity with time since the 1969 Coal Mine Health and Safety Act took effect is statistically significant at the 99.0 percent confidence level. The results for the regression using a join point of 20 (1969) are (figures in parentheses are standard error):

$$\text{(1)}\ \ PRY_t = \underset{(0.509)}{6.189} + \underset{(0.0405)^{****}}{0.5279X_1} - \underset{(0.180)^{****}}{2.048X_2}(X_1 - 20)$$

$R^2 = 0.887$

F-statistic (2,23) = 90.48

Standard error of the regression = 1.12

****Significant at the 99.0 percent confidence level.

Since productivity actually reached a peak in 1967, the piecewise model may be used to determine whether the break in trend is more significant in 1967 or 1969 by using two join points - 18 (1967) and 20 (1969). The results are:

$$\text{(1A)}\ PRY_t = \underset{(0.280)}{5.345} + \underset{(0.0256)^{****}}{0.6499X_1} - \underset{(0.246)^{****}}{1.996X_2}(X_1 - 18) +$$

$$\underset{(0.312)}{0.379X_3}(X_1 - 20)$$

$R^2 = 0.972$

F-statistic (3,22) = 252.64

Standard error of the regression = 0.572

****Significant at the 99.0 percent confidence level.

The results of this regression indicate that the break in trend in 1967 is significant at the 99.0 percent confidence level, while that in 1969 is not significant. Thus, the downturn began before the CMHSA and the Act can at most be considered to have reenforced an existing trend.

The percent of coal mined by continuous miners (Figure 2) shows a strong increasing trend over the entire 26-year period (1950 through 1975). Although weighted-average seam thickness (Figure 3) varies only slightly over the time period (maximum - 5.3 feet, minimum - 5.0 feet), there is an overall increasing trend. Weighted-average days in operation (Figure 4) shows no strong trend, although there is a slight, positive slope overall. Average production (Figure 5) has an increasing trend through 1956, then a decreasing trend through 1963, then an increasing trend through 1973, and finally a decreasing trend to 1975. Piecewise regression analysis reveals that the breaks in trend in 1956, 1963, and 1973 are all significant at confidence levels of 99.0 percent. The actual price of coal in West Virginia (Figure 6) shows a gradually declining trend through 1969; since 1969, the price of coal has risen steeply,

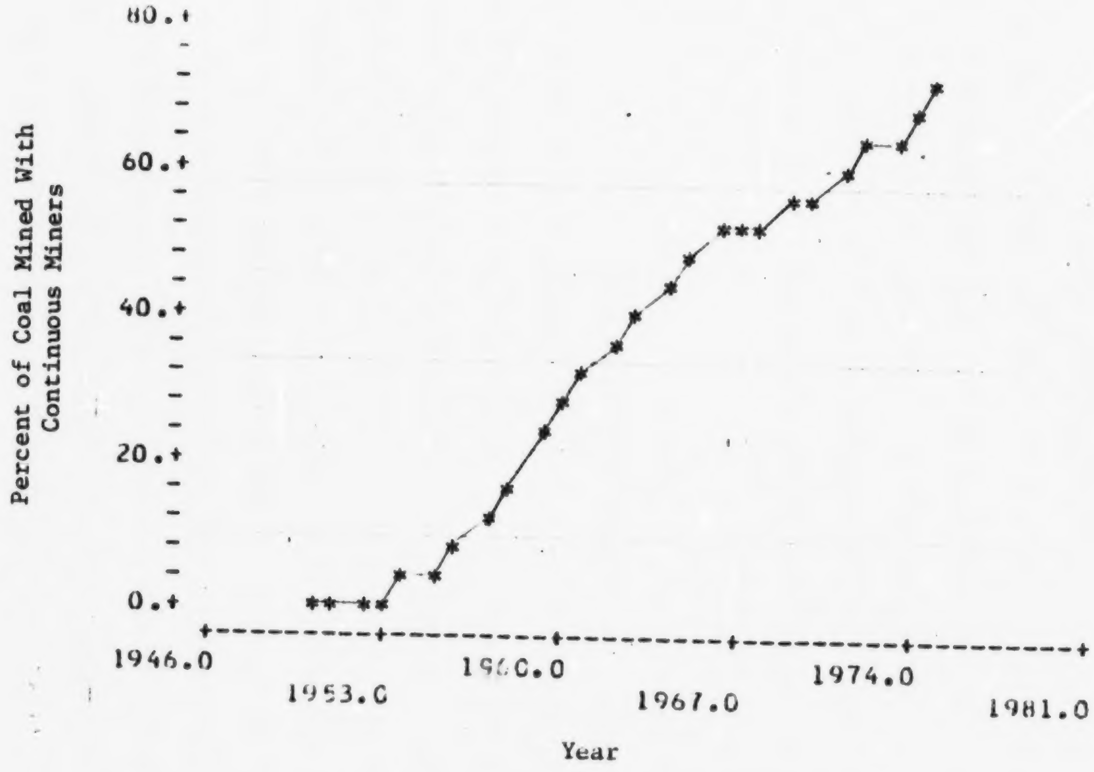


Figure 2 . Trend of Percent of Coal Mined With Continuous Miners: West Virginia (1950 Through 1975)

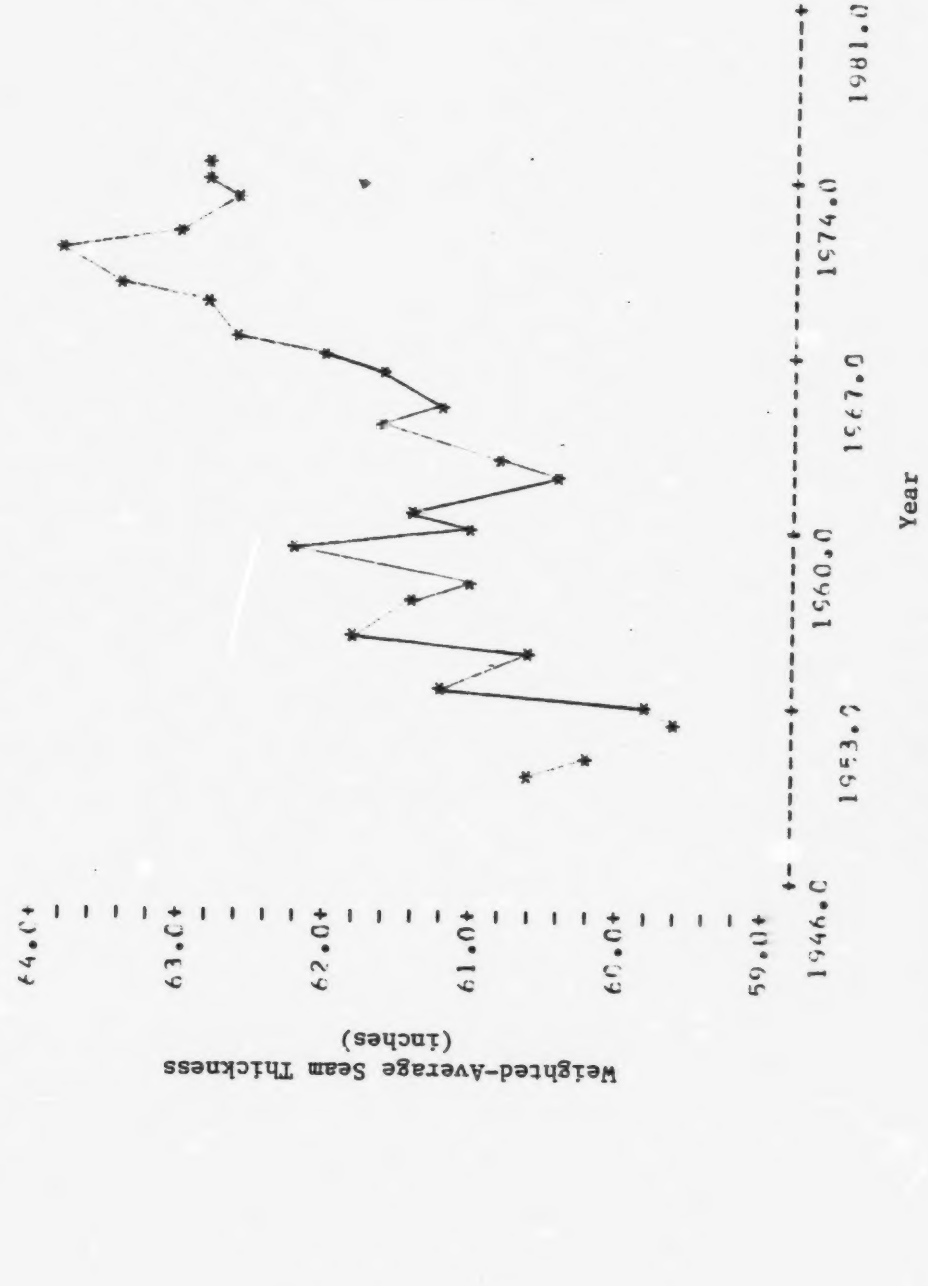


Figure 3 . Trend of Weighted-Average Seam Thickness: West Virginia (1950 Through 1975)

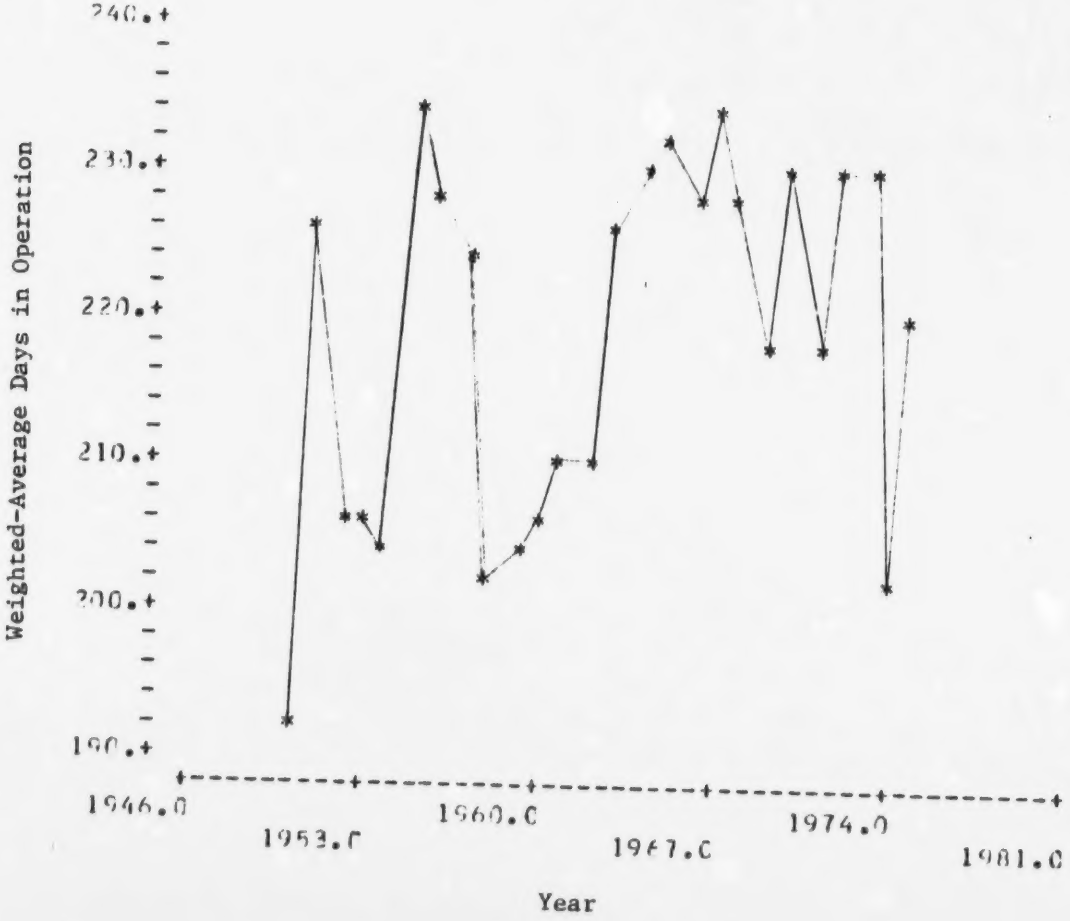


Figure 4 . Trend of Weighted-Average Days in Operation: West Virginia (1950 Through 1975)

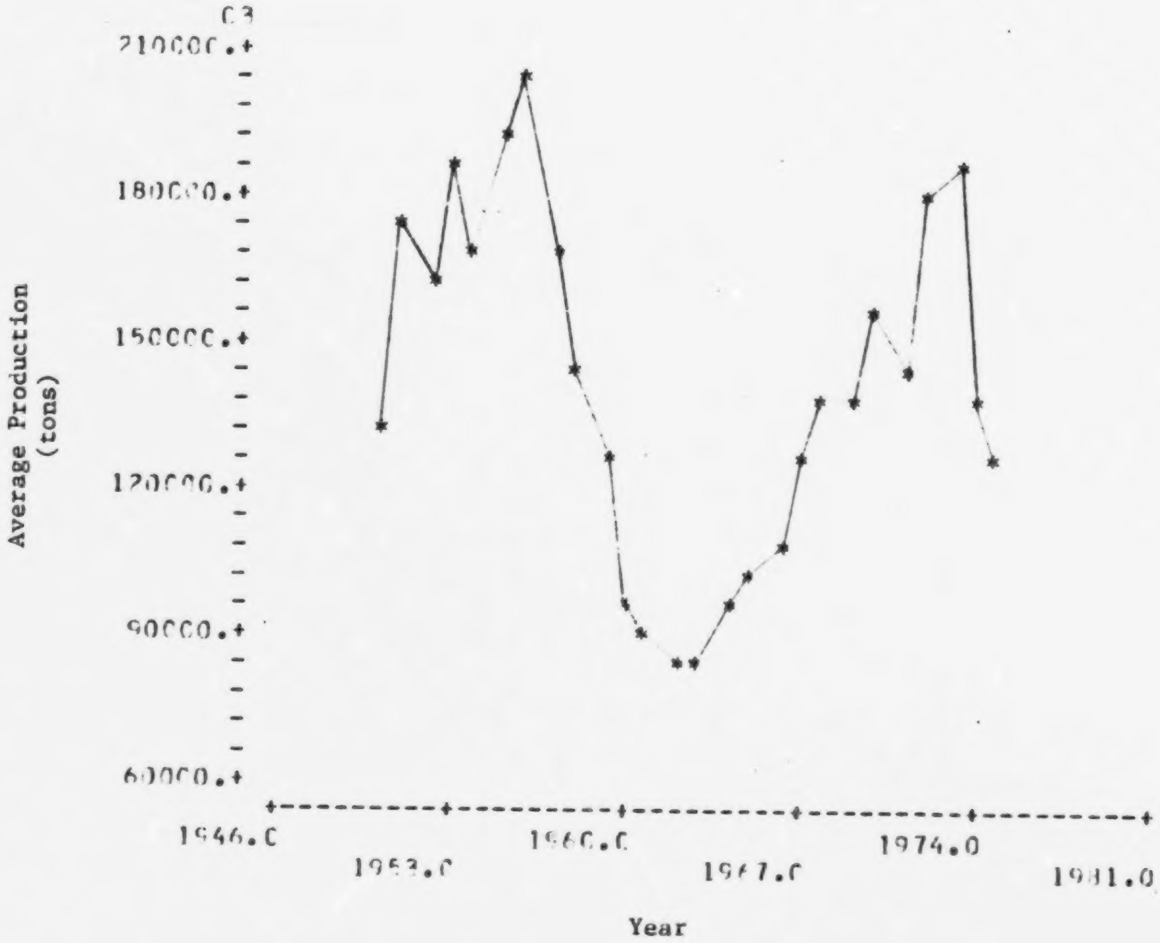


Figure 5 . Trend of Average Production: West Virginia (1950 Through 1975)

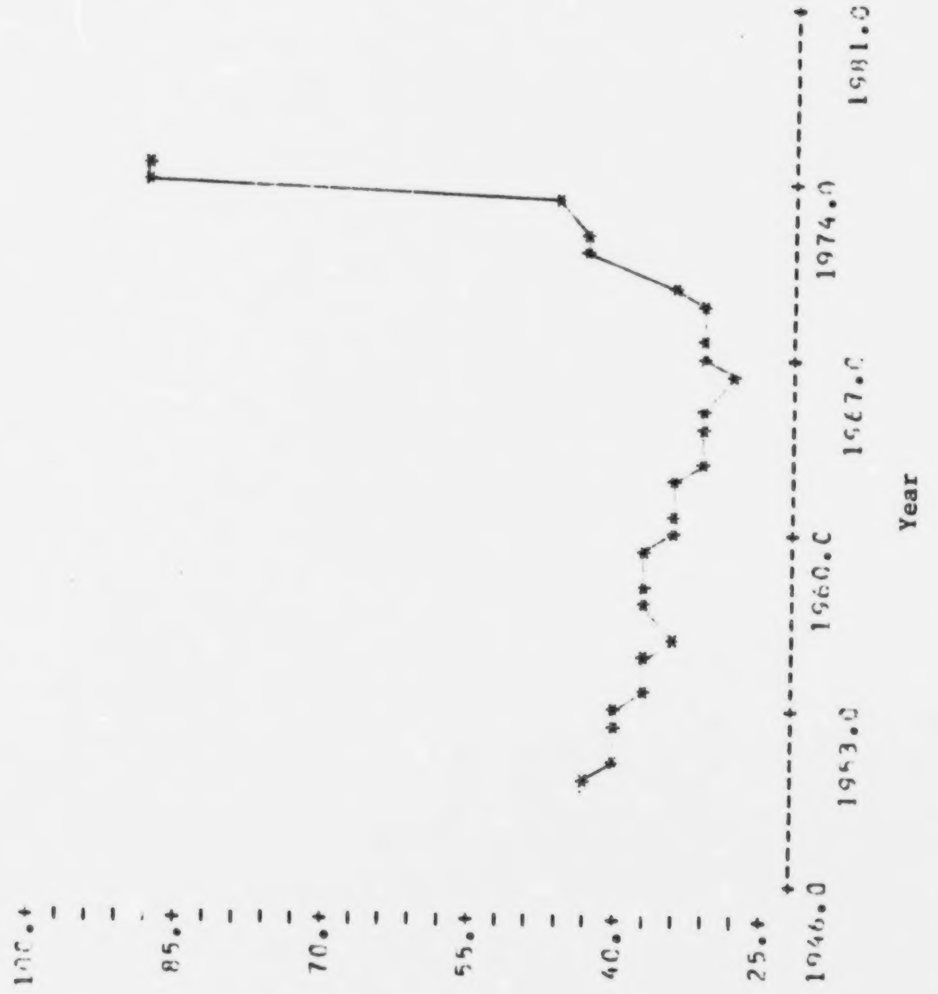


Figure 6 . Trend of the Price of Coal: West Virginia (1950 Through 1975) especially in 1974. A break in trend in 1969 is statistically significant at the 99.0 percent confidence level. Under the assumption that there had been no Health and Safety Act in the years 1970 through 1975, estimates indicate that the cost of coal would be decreased by approximately 20.0 percent (Fettig, 1978, p. 53; see Table 1). The resulting price has essentially the same trend as the actual price; however, the increases are not as large (Figure 7).

Results of Regression for 1950 Through 1975

The results for the ordinary least squares (OLS) regression of the full multivariate model for the years 1950 through 1975 follow.

$$\begin{aligned}(2)\ PRY_t = {} & \underset{(35.9671)}{13.8692} + \underset{(16.6759)*}{30.2489AP_t} - \underset{(0.576421)}{0.0529401ST_t} \\ & + \underset{(0.0459441)\#\#}{0.0882756CM_t} - \underset{(0.0330894)}{0.0280457DO_t} - \underset{(0.0544488)\#}{0.0904548PR} \\ & - \underset{(0.0583311)}{0.0738767MACT_t}\end{aligned}$$

$R^2 = 0.8613$

F-statistic (6,19) = 19.6704

Durbin-Watson statistic = 1.1466

Standard error of the regression = 1.36430

Sum of squared residuals = 35.3651.

The coefficient of percent of coal mined by continuous miners is positive and significant at the 95.0 percent confidence level, the coefficient of price is negative and significant at the 90.0 percent confidence level, and the coefficient of average production is negative and significant at the 90.0 percent confidence level. The other coefficients are not significant. All variables except

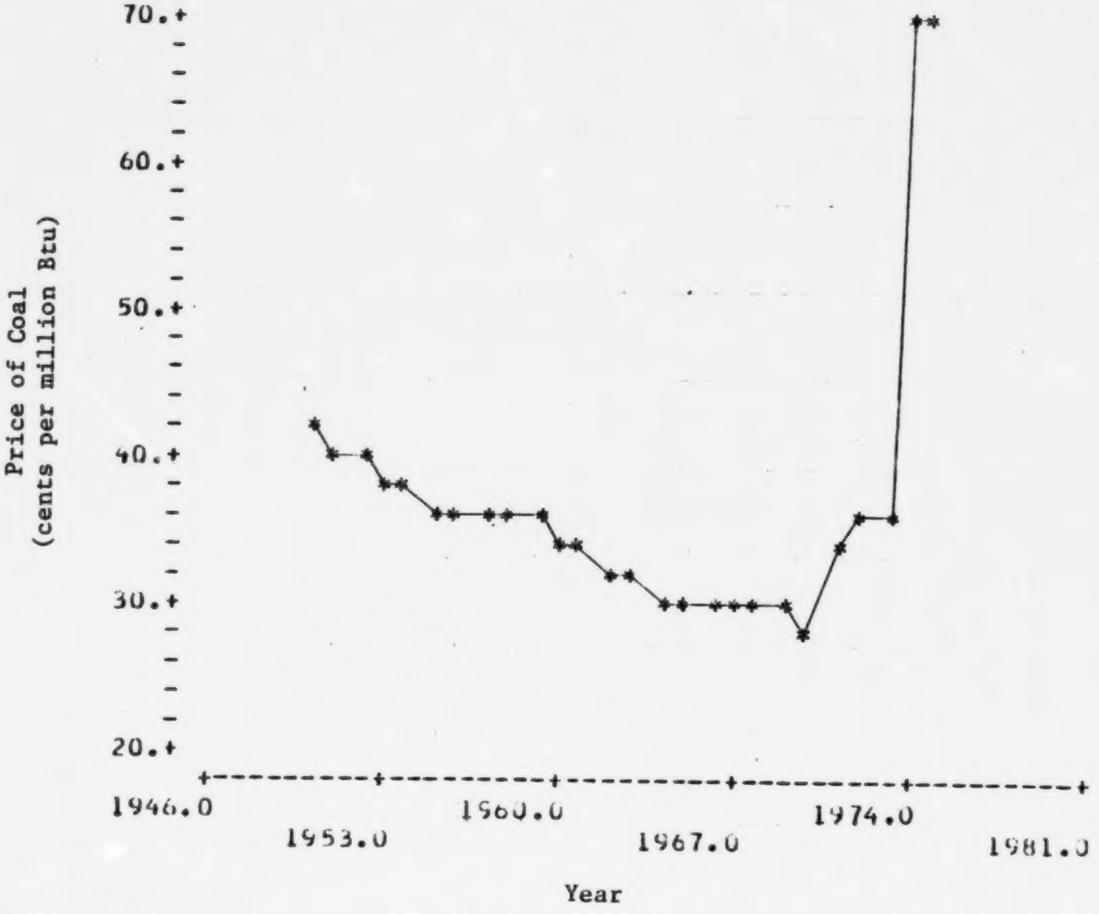


Figure 7. Trend of the Price of Coal Assuming No CMHSA: West Virginia (1950 Through 1975)

weighted-average seam thickness and average production have coefficients with the expected signs. The F-statistic indicates that the equation is significant at the 99.0 percent confidence level, and approximately 86.0 percent of the variance is explained. The Durbin-Watson statistic for autocorrelation is in the inconclusive region; however, the Hart-von Neumann test indicates positive autocorrelation (99.0 percent confidence level). The pairwise correlation matrix, Table 2 , indicates significant correlation between weighted-average seam thickness and percent mined by continuous miners (0.81); otherwise, the correlations appear low. A plot of actual and fitted values and a plot of the residuals are presented in Figure 8 . The residuals plot gives no indication of the presence of heteroskedasticity.

The Cochrane-Orcutt iterative method was used to correct for the problem of positive autocorrelation. The results follow.

$$
\begin{aligned}
(3)\ PRY_t = {} & \underset{(20.1472)}{24.0800} - \underset{(15.1792)}{12.7845AP_t} - \underset{(0.320902)}{0.0195922ST_t} \\
& - \underset{(0.0699646)}{0.0695448CM_t} - \underset{(0.0202887)}{0.00824513DO_t} - \underset{(0.0394551)\#}{0.062597PR_t} \\
& + \underset{(0.0458691)}{0.0172795MACT_t}
\end{aligned}
$$

$R^2 = 0.9287$

F-statistic (6,18) = 39.0687

Durbin-Watson statistic = 1.2863

Standard error of the regression = 0.942323

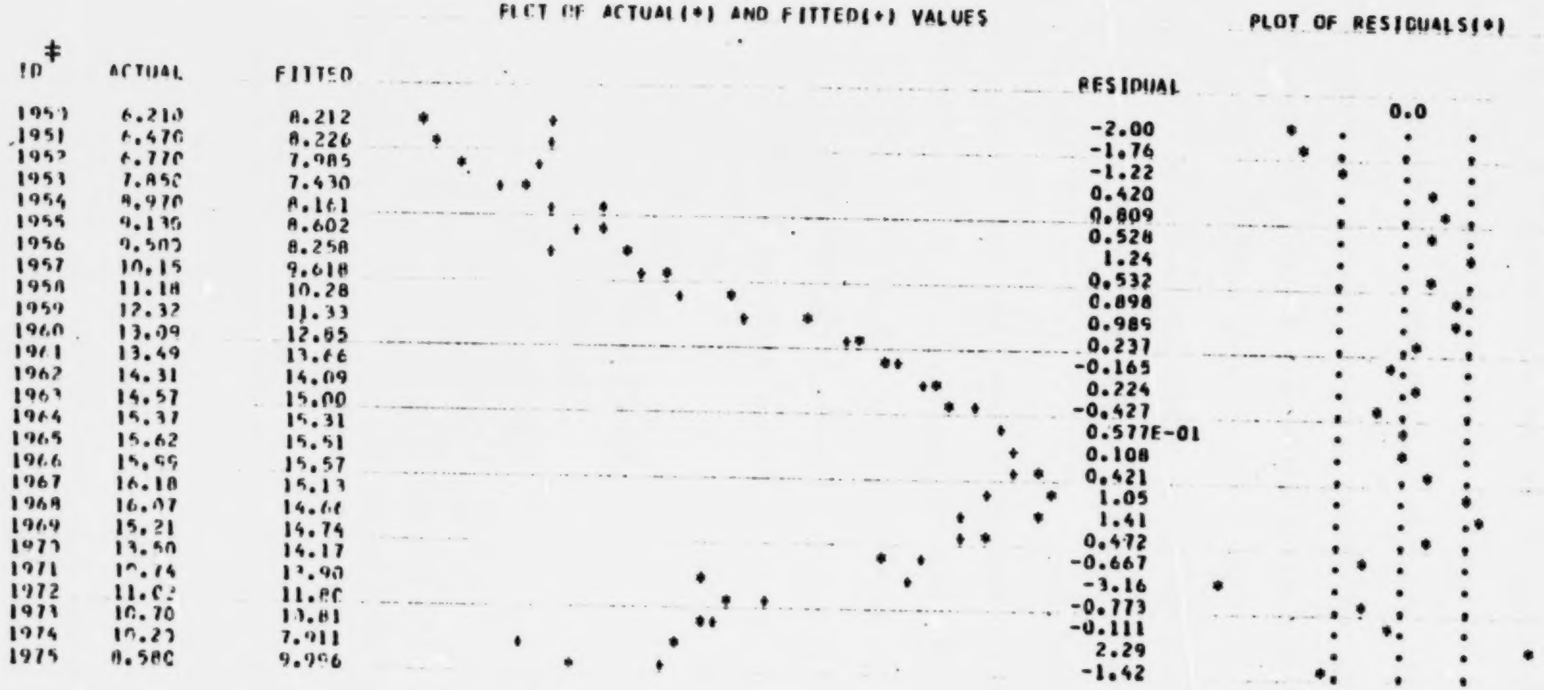
Sum of squared residuals = 15.9835.

The coefficient of price is significant at the 90.0 percent confidence level and has the expected negative sign. Other coefficients

Table 2

Pairwise Correlation Matrix for AP, ST, CM, DO, PR, and MACT: West Virginia
(1950 Through 1975)

	AP	ST	CM	DO	PR	MACT
AP	1.0000	0.026270	-0.32900	0.13422	0.089512	0.17476
ST	0.026270	1.0001	0.80675	0.31557	0.10332	0.52174
CM	-0.32900	0.80675	1.0000	0.38741	0.14978	0.61665
DO	0.13422	0.31557	0.38741	1.0000	-0.36983	0.019904
PR	0.089512	0.10332	0.14978	-0.36983	1.0000	0.71945
MACT	0.17476	0.52174	0.61665	0.019904	0.71945	1.0000



ID‡	ACTUAL	FITTED	RESIDUAL
1950	6.210	8.212	-2.00
1951	6.470	8.226	-1.76
1952	6.770	7.985	-1.22
1953	7.850	7.430	0.420
1954	8.970	8.161	0.809
1955	9.130	8.602	0.528
1956	9.503	8.258	1.24
1957	10.15	9.618	0.532
1958	11.18	10.28	0.898
1959	12.32	11.33	0.989
1960	13.09	12.85	0.237
1961	13.49	13.66	-0.165
1962	14.31	14.09	0.224
1963	14.57	15.00	-0.427
1964	15.37	15.31	0.577E-01
1965	15.62	15.51	0.108
1966	15.99	15.57	0.421
1967	16.18	15.13	1.05
1968	16.07	14.66	1.41
1969	15.21	14.74	0.472
1970	13.50	14.17	-0.667
1971	10.74	13.90	-3.16
1972	11.02	11.80	-0.773
1973	10.70	10.81	-0.111
1974	10.20	7.911	2.29
1975	8.580	9.996	-1.42

Figure 8 . Plots for Productivity Model, 1950 Through 1975: West Virginia (OLS)

‡"ID" refers to the year of the observation in all figures with plots for regression results.

have unexpected signs but are not significant. The F-statistic indicates that the equation is significant at the 99.0 percent confidence level, and over 92.0 percent of the variance is explained. The Durbin-Watson statistic is in the inconclusive region, but the Hart-von Neumann test indicates that positive autocorrelation is still present (95.0 percent confidence level). A plot of actual and fitted values and a plot of the residuals are presented in Figure 9. The residuals plot gives no indication of the presence of heteroskedasticity.

The principal components method was used to correct for multicollinearity. Average production, weighted-average seam thickness, percent mined by continuous miners, weighted-average days in operation, and price were combined into one variable, PC. The factor loadings for the principal component and the results of the OLS regression follow.

Variable	Factor Loadings
AP	0.19749
ST	-0.88700
CM	-0.94695
DO	-0.58350
PR	-0.00001

$$(4)\ PRY_t = \underset{(0.422833)}{12.6157} - \underset{(0.439049)^{****}}{2.91602PC_t} - \underset{(0.0287516)^{\#\#\#\#\#}}{0.138758MACT_t}$$

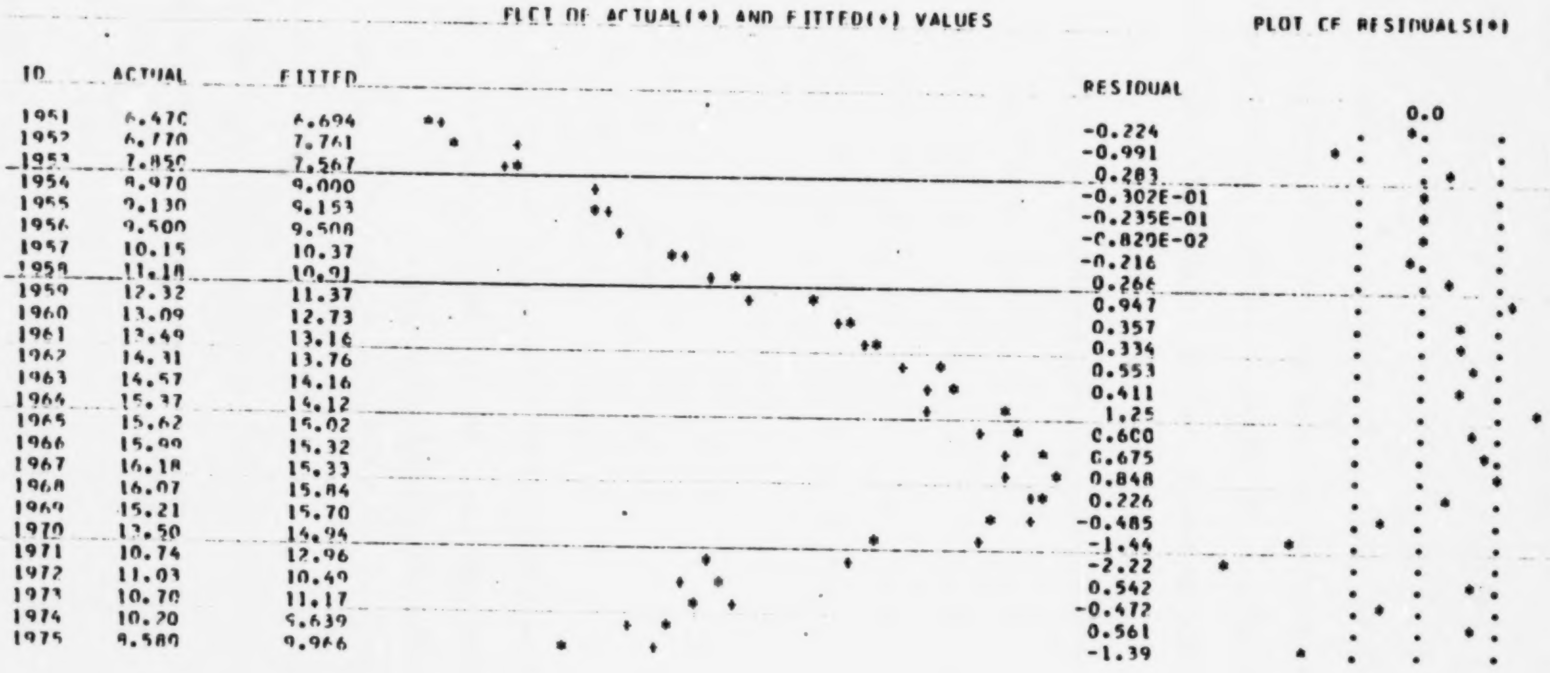
$R^2 = 0.6724$

F-statistic (2,23) = 23.6087

Durbin-Watson statistic = 0.9100

Standard error of the regression = 1.90583

Sum of squared residuals = 83.5404.



```
                           PLOT OF ACTUAL(*) AND FITTED(+) VALUES                 PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                          RESIDUAL
                                                                                              0.0
1951    6.470       6.694                                           -0.224
1952    6.770       7.761                                           -0.991
1953    7.850       7.567                                            0.283
1954    8.970       9.000                                           -0.302E-01
1955    9.130       9.153                                           -0.235E-01
1956    9.500       9.508                                           -0.820E-02
1957    10.15       10.37                                           -0.216
1958    11.18       10.91                                            0.266
1959    12.32       11.37                                            0.947
1960    13.09       12.73                                            0.357
1961    13.49       13.16                                            0.334
1962    14.31       13.76                                            0.553
1963    14.57       14.16                                            0.411
1964    15.37       14.12                                              1.25
1965    15.62       15.02                                            0.600
1966    15.99       15.32                                            0.675
1967    16.18       15.33                                            0.848
1968    16.07       15.84                                            0.226
1969    15.21       15.70                                           -0.485
1970    13.50       14.94                                             -1.44
1971    10.74       12.96                                             -2.22
1972    11.03       10.49                                            0.542
1973    10.70       11.17                                           -0.472
1974    10.20       9.639                                            0.561
1975    8.580       9.966                                             -1.39
```

Figure 9 . Plots for Productivity Model, 1950 Through 1975: West Virginia (CORC)

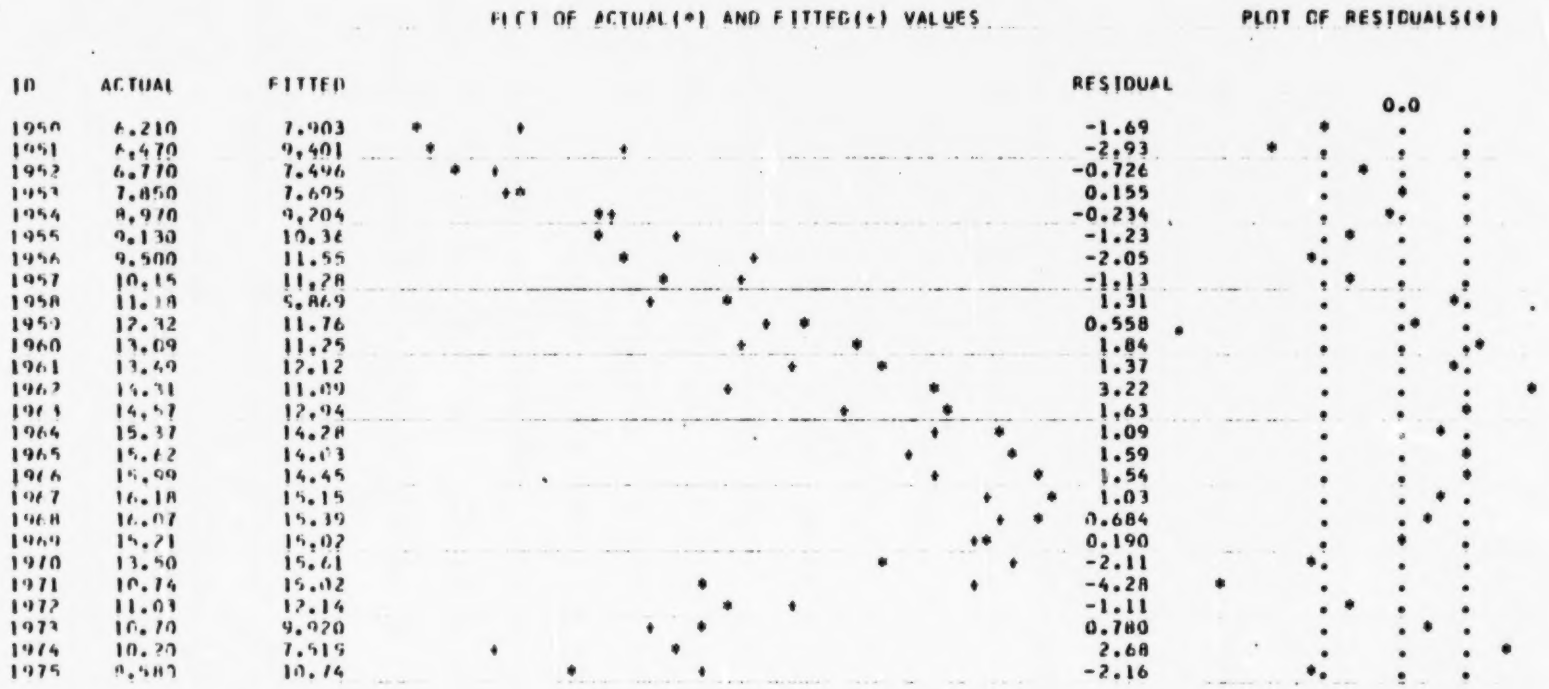
Coefficients of both the principal component and the Mine-Act variable are significant at the 99.0 and 99.5 percent confidence level, respectively. The expected sign of the principal component is indeterminate, since it is composed of variables having both expected positive and negative (price) relationships to the dependent variable. The Mine-Act variable has the expected sign. The F-statistic indicates that the equation is significant at the 99.0 percent confidence level. The results show a lower explanatory power ($R^2 = 0.67$) than Equation 2 without the principal component ($R^2 = 0.86$). The Durbin-Watson statistic indicates positive autocorrelation (99.0 percent confidence level). The pairwise correlation matrix below indicates that the degree of correlation between the principal component and the Mine-Act variable is low.

	PC	MACT
PC	1.0000	-0.49628
MACT	-0.49628	1.0000

A plot of actual and fitted values and a plot of the residuals are presented in Figure 10. The residuals plot gives no indication of the presence of heteroskedasticity.

Correction for both multicollinearity and autocorrelation by simultaneously using principal components and the Cochrane-Orcutt iterative method yields the following results.

$$(5)\ PRY_t = \underset{(1.92672)}{13.8416} + \underset{(0.540559)}{0.485050}PC_t - \underset{(0.0318410)}{0.0349237}MACT_t$$



ID	ACTUAL	FITTED	RESIDUAL
1950	6.210	7.903	-1.69
1951	6.470	9.401	-2.93
1952	6.770	7.496	-0.726
1953	7.850	7.695	0.155
1954	8.970	9.204	-0.234
1955	9.130	10.36	-1.23
1956	9.500	11.55	-2.05
1957	10.15	11.28	-1.13
1958	11.18	9.869	1.31
1959	12.32	11.76	0.558
1960	13.09	11.25	1.84
1961	13.49	12.12	1.37
1962	14.31	11.09	3.22
1963	14.57	12.94	1.63
1964	15.37	14.28	1.09
1965	15.62	14.03	1.59
1966	15.99	14.45	1.54
1967	16.18	15.15	1.03
1968	16.07	15.39	0.684
1969	15.21	15.02	0.190
1970	13.50	15.61	-2.11
1971	10.74	15.02	-4.28
1972	11.03	12.14	-1.11
1973	10.70	9.920	0.780
1974	10.20	7.519	2.68
1975	8.583	10.74	-2.16

Figure 10. Plots for Productivity Model Using Principal Components, 1950 Through 1975: West Virginia (OLS)

$R^2 = 0.9163$

F-statistic (2,22) = 120.363

Durbin-Watson statistic = 1.0888

Standard error of the regression = 0.923640

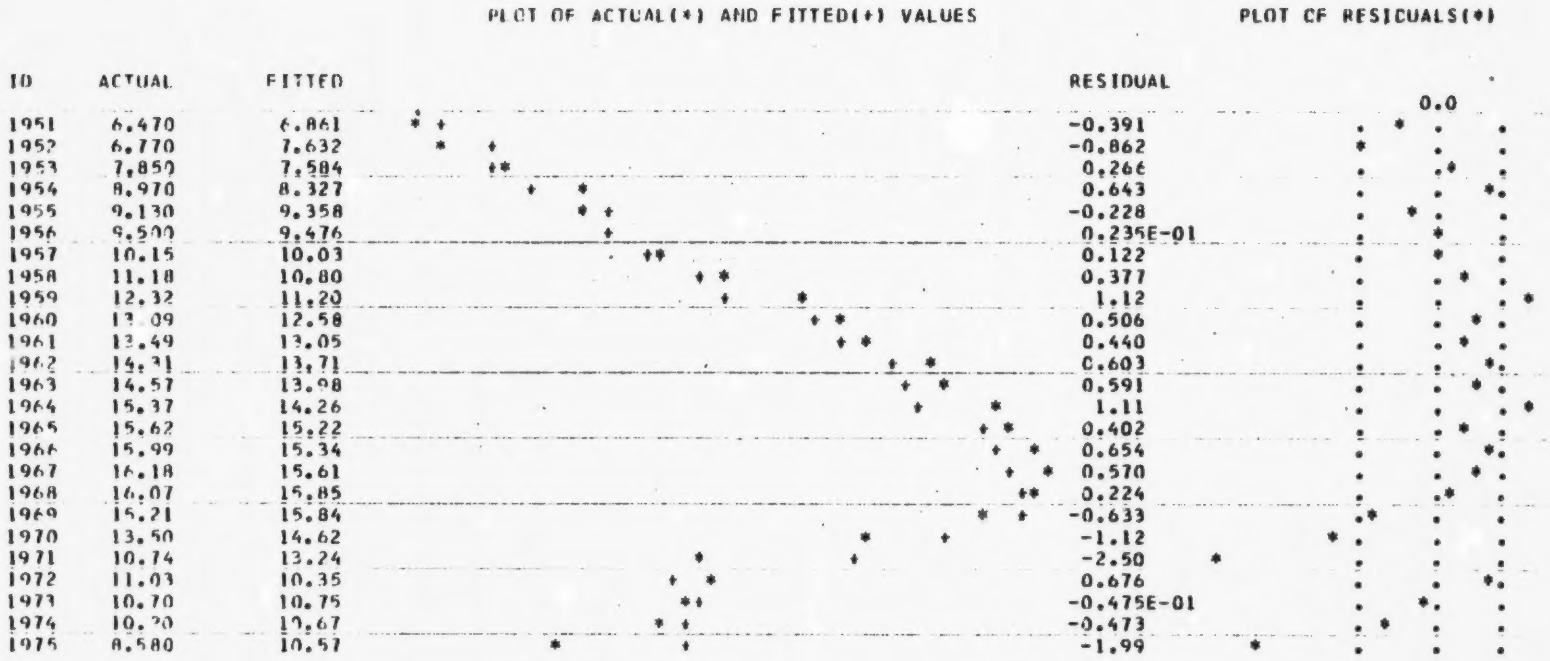
Sum of squared residuals = 18.7684.

Neither the principal component nor the Mine Act are significant; however, the equation explains over 91.0 percent of the variance and is significant at the 99.0 percent confidence level. The Durbin-Watson statistic indicates positive autocorrelation (95.0 percent confidence level). A plot of actual and fitted values and a plot of the residuals are presented in Figure 11.

Examination of the data for weighted-average seam thickness reveals that the maximum is 5.3 feet and the minimum is approximately 5.0 feet, a variation of only 0.3 feet (Table 1). I consider seam thickness to be essentially a constant over the period of investigation, since the variation is only a few inches. This small variation is not likely to have a marked effect on productivity; furthermore, the variable ST does not show significance in the full model (Equations 2 and 3). The results for the OLS regression of the model with seam thickness eliminated are:

$$(6)\ \mathrm{PRY}_t = \underset{(6.52369)}{10.6235} - \underset{(11.8148)^{***}}{31.3010\mathrm{AP}_t} + \underset{(0.0261881)\#\#\#\#\#}{0.0847397\mathrm{CM}_t}$$

$$+ \underset{(0.0293793)}{0.0293009\mathrm{DO}_t} - \underset{(0.0520490)\#\#}{0.0914366\mathrm{PR}_t} - \underset{(0.0508989)\#}{0.0714877\mathrm{MACT}_t}$$



```
ID      ACTUAL     FITTED      RESIDUAL
1951    6.470      6.861       -0.391
1952    6.770      7.632       -0.862
1953    7.850      7.584        0.266
1954    8.970      8.327        0.643
1955    9.130      9.358       -0.228
1956    9.500      9.476        0.235E-01
1957    10.15      10.03        0.122
1958    11.18      10.80        0.377
1959    12.32      11.20         1.12
1960    13.09      12.58        0.506
1961    13.49      13.05        0.440
1962    14.31      13.71        0.603
1963    14.57      13.98        0.591
1964    15.37      14.26         1.11
1965    15.62      15.22        0.402
1966    15.99      15.34        0.654
1967    16.18      15.61        0.570
1968    16.07      15.85        0.224
1969    15.21      15.84       -0.633
1970    13.50      14.62        -1.12
1971    10.74      13.24        -2.50
1972    11.03      10.35        0.676
1973    10.70      10.75       -0.475E-01
1974    10.20      10.67       -0.473
1975    8.580      10.57        -1.99
```

Figure 11. Plots for Productivity Model Using Principal Components, 1950 Through 1975: West Virginia (CORC)

$R^2 = 0.8614$

F-statistic (5,20) = 24.8341

Durbin-Watson statistic = 1.1507

Standard error of the regression = 1.33005

Sum of squared residuals = 35.3808.

The percent of coal mined by continuous miners has a positive coefficient that is significant at the 99.5 percent confidence level. The coefficient of average production is again negative and significant at the 98.0 percent confidence level. The coefficients of price and the Mine Act variable are negative and significant at the 95.0 and 90.0 percent confidence levels, respectively. The coefficient of weighted-average days in operation is not significant. The equation is significant at the 99.0 percent confidence level and over 86.0 percent of the variance is explained. The Durbin-Watson statistic is in the inconclusive region; however, positive autocorrelation is indicated by the Hart-von Neumann test (99.0 percent confidence level). No significant pairwise correlation remains in the correlation matrix (not shown) since seam thickness has been eliminated. A plot of actual and fitted values and a plot of the residuals are presented in Figure 12. No sign of heteroskedasticity is evident in the residuals plot. plot.

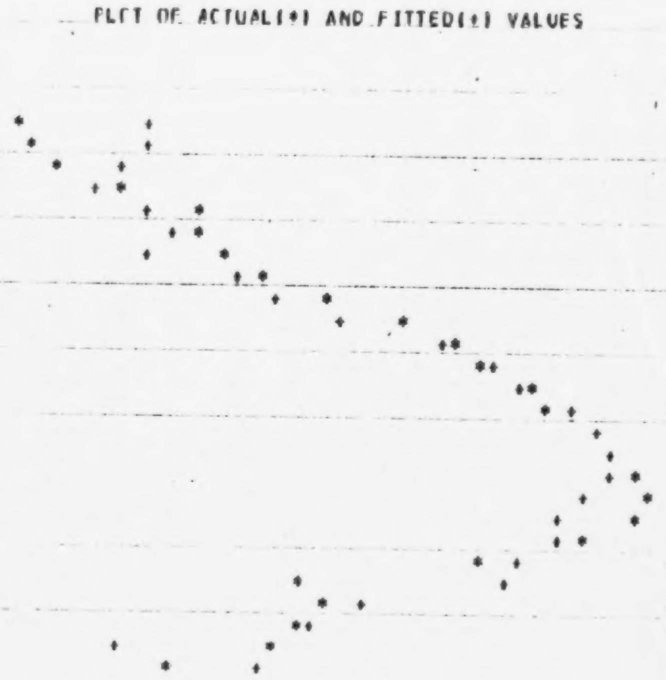
Attempting to correct for autocorrelation with the Cochrane-Orcutt iterative method yields the following results.

$$(7)\ PRY_t = \underset{(5.88368)}{22.8922} - \underset{(14.0094)}{13.0837AP_t} - \underset{(0.0647235)}{0.0706855CM_t}$$

$$- \underset{(0.0191267)}{0.00793582DO_t} - \underset{(0.378180)\#}{0.0629780PR_t} + \underset{(0.0423966)}{0.0181496MACT_t}$$

```
ID      ACTUAL      FITTED      RESIDUAL

1950     6.210       8.230       -2.02
1951     6.470       8.222       -1.75
1952     6.770       7.935       -1.16
1953     7.850       7.372        0.478
1954     8.970       8.187        0.783
1955     9.130       8.598        0.532
1956     9.500       8.293        1.21
1957    10.15        9.649        0.501
1958    11.18       10.27         0.907
1959    12.32       11.38         0.942
1960    13.39       12.86         0.231
1961    13.49       13.67        -0.182
1962    14.31       14.05         0.259
1963    14.57       15.00        -0.431
1964    15.37       15.33         0.401E-01
1965    15.62       15.49         0.129
1966    15.99       15.55         0.436
1967    16.18       15.12         1.06
1968    16.07       14.65         1.42
1969    15.21       14.72         0.494
1970    13.50       14.19        -0.689
1971    10.74       13.92        -3.18
1972    11.03       11.80        -0.767
1973    10.70       10.80        -0.104
1974    10.20        7.913        2.29
1975     8.580       9.997       -1.42
```



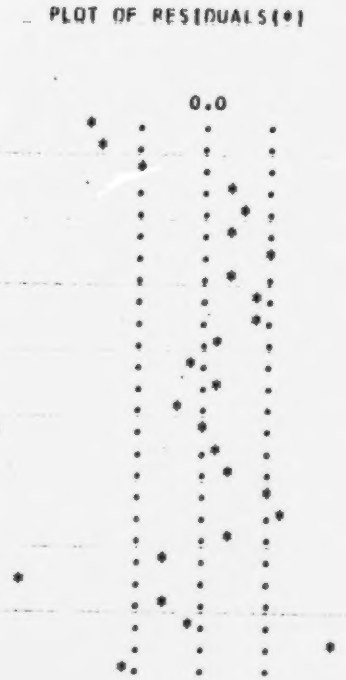


Figure 12. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1975: West Virginia (OLS)

$R^2 = 0.9287$

F-statistic (5,19) = 49.4726

Durbin-Watson statistic = 1.2834

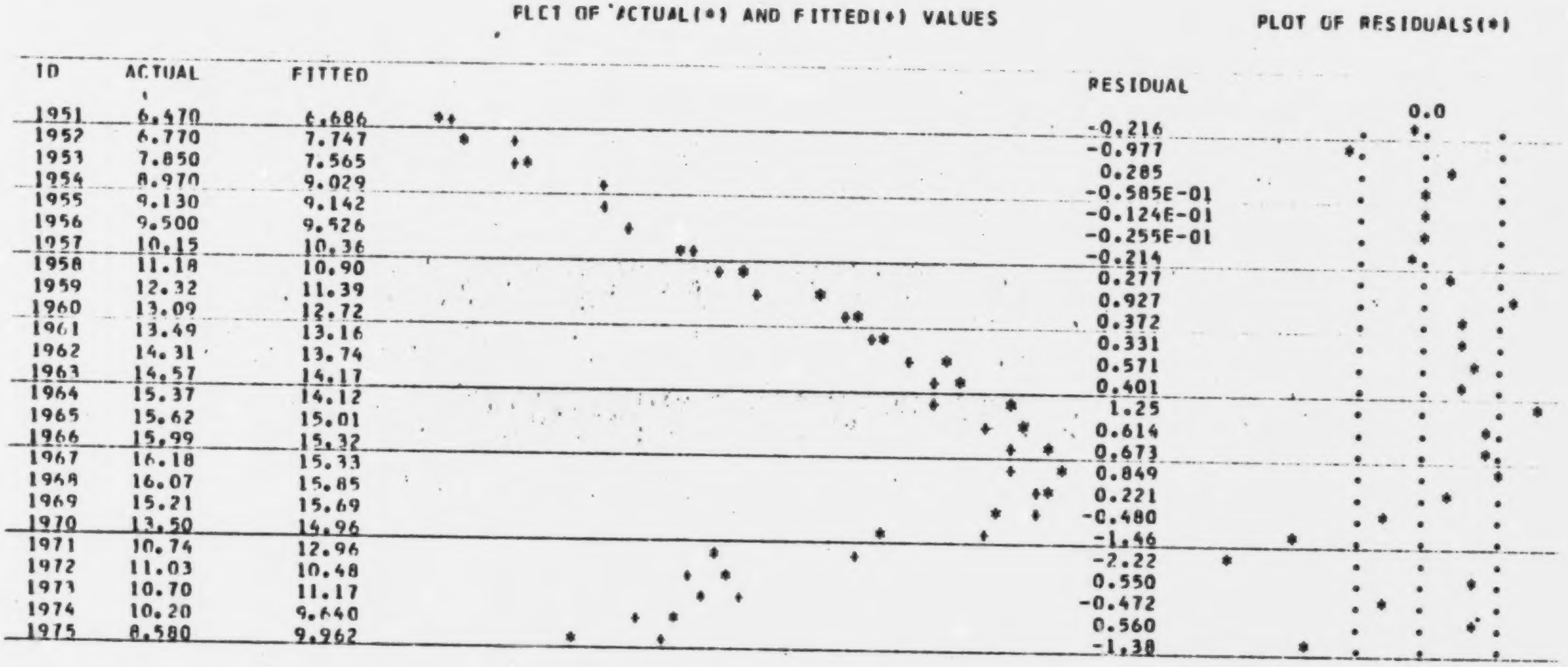
Standard error of the regression = 0.917314

Sum of squared residuals = 15.9878.

Only price remains significant (90.0 percent confidence level). All of the other variables have coefficients with unexpected signs; however, since they are not significant, this presents no serious problem. The equation is significant at the 99.0 percent confidence level, and almost 93.0 percent of the variance is explained. The Durbin-Watson statistic is in the inconclusive region, but the Hart-von Neumann test indicates that positive autocorrelation is still present (95.0 percent confidence level). A plot of actual and fitted values and a plot of the residuals are presented in Figure 13. The residuals plot does not indicate the presence of heteroskedasticity.

Since correlation among variables is low, use of the method of principal components was not considered essential in this case. However, the regression was carried out, but the results were not an improvement over those presented in Equations 6 and 7.

A comparison of the results for Equations 2 and 6 indicates that the weighted-average seam thickness variable is not significant in explaining productivity in West Virginia for 1950 through 1975. The F-statistic for testing the hypothesis that the coefficient of ST equals zero is 0.01. Since 0.01 is less than the critical F (1,19; 0.05) value of 4.38, the hypothesis cannot be rejected.



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                                  PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID      ACTUAL      FITTED                                               RESIDUAL
                                                                                          0.0
1951    6.470       6.686                                                -0.216
1952    6.770       7.747                                                -0.977
1953    7.850       7.565                                                 0.285
1954    8.970       9.029                                                -0.585E-01
1955    9.130       9.142                                                -0.124E-01
1956    9.500       9.526                                                -0.255E-01
1957   10.15       10.36                                                 -0.214
1958   11.18       10.90                                                  0.277
1959   12.32       11.39                                                  0.927
1960   13.09       12.72                                                  0.372
1961   13.49       13.16                                                  0.331
1962   14.31       13.74                                                  0.571
1963   14.57       14.17                                                  0.401
1964   15.37       14.12                                                  1.25
1965   15.62       15.01                                                  0.614
1966   15.99       15.32                                                  0.673
1967   16.18       15.33                                                  0.849
1968   16.07       15.85                                                  0.221
1969   15.21       15.69                                                 -0.480
1970   13.50       14.96                                                 -1.46
1971   10.74       12.96                                                 -2.22
1972   11.03       10.48                                                  0.550
1973   10.70       11.17                                                 -0.472
1974   10.20        9.640                                                 0.560
1975    8.580       9.962                                                -1.38
```

Figure 13. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1975: West Virginia (CORC)

Results of Regressions for 1950 Through 1969 and Predictions of Productivity

This section derives predictions of productivity levels that might have been obtained in 1970 through 1975 if the 1969 Coal Mine Health and Safety Act had not been passed. Three approaches are employed. First, time trends of productivity from 1950 through 1969 are used to predict possible levels of productivity; second, estimates of the multivariate model were made using values of the independent variables for 1950 through 1969. Predictions of productivity in the absence of new federal legislation were made using values of the independent variables in 1970 through 1975 and compared to actual levels of productivity. Third, predictions are made based on the results of the model for 1950 through 1975 by subtracting the negative influence of MACT on productivity, and these are compared to actual values.

It is possible that the legislation could have indirect effects on productivity by affecting the other independent variables in some way. If so, this could affect the predictions. To investigate whether such influences prevail, the trend of each variable was reexamined. Returning to Figure 2, the percent of coal mined by continuous miners shows a strongly increasing trend over the whole time period, with no break in trend in 1969. Weighted-average seam thickness (Figure 3) shows no break in trend in 1969. No break in trend is evidenced in 1969 for weighted-average days in operation (Figure 4) or average production (Figure 5). These trend analyses suggest that the Mine Act is unlikely to have seriously affected these variables. Theoretically, the mine-size variable could have been affected to some degree by the legislation since one might expect the increasing trend of average production to change to a higher slope after the passage of the Act due to the closure of higher cost, small mines unable to remain economic while complying with the regulations. However, the variable average production shows no change in trend in 1969 or thereafter (Figure 5).[3] The actual price of coal is certain to have been affected by the Mine Act, since the Mine Act directly caused higher mining costs. However, the estimated magnitude of this effect has been incorporated into the analysis by subtracting out the estimated portion of the actual cost that was due to the existence of the Mine Act in 1970 through 1975. The presence of this Act impact adjustment in the analysis and the absence of changes in the trend of other variables suggests that the Act had limited indirect effects.

Productivity shows an increasing trend with time through 1967; after 1967 it begins to decrease. However, the declines in 1968 and 1969 are slight compared to those occurring after 1969. A simple regression of productivity with time (T) from 1 (1950) through 20 (1969) was run. The results are:

$$(8)\ PRY_t = \underset{(0.363)}{5.808} + \underset{(0.0303)^{****}}{0.5823T}$$

$R^2 = 0.9535$

F-statistic (1,18) = 368.74

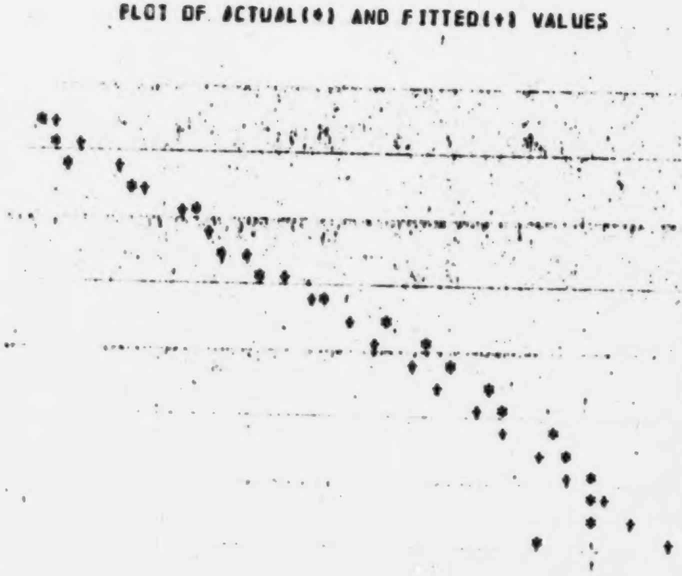
Durbin-Watson statistic = 0.4184

Standard error of the regression = 0.7820

Sum of squared residuals = 11.0073.

This regression produces a residuals plot that shows a strong "u" shape (Figure 14), indicative of a high degree of positive

ID	ACTUAL	FITTED	RESIDUAL
1950	6.210	6.391	-0.181
1951	6.470	6.973	-0.503
1952	6.770	7.555	-0.785
1953	7.850	8.137	-0.287
1954	8.970	8.720	0.250
1955	9.130	9.302	-0.172
1956	9.500	5.884	-0.384
1957	10.15	10.47	-0.317
1958	11.18	11.05	0.131
1959	12.32	11.63	0.689
1960	13.09	12.21	0.876
1961	13.49	12.80	0.694
1962	14.31	13.38	0.932
1963	14.57	13.96	0.609
1964	15.37	14.54	0.827
1965	15.62	15.13	0.495
1966	15.99	15.71	0.283
1967	16.18	16.29	-0.110
1968	16.07	16.87	-0.802
1969	15.21	17.45	-2.24



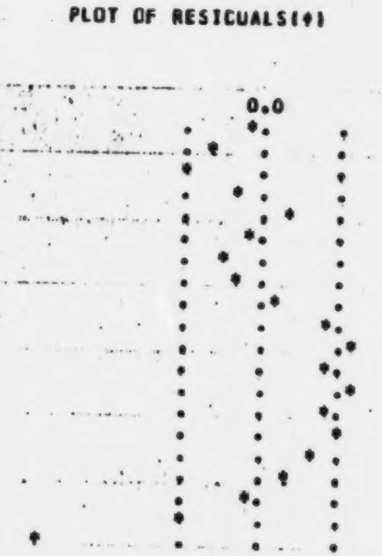


Figure 14. Plots for Time Trend of Productivity, 1950 Through 1969: West Virginia (OLS)

autocorrelation. This is confirmed by the Durbin-Watson statistic (99.0 percent confidence level). Application of the Cochrane-Orcutt technique does not eliminate the positive autocorrelation. A higher degree equation is used to best explain the variation in productivity in these years. This could be anticipated because the trend shown in Figure 14 is actually not linear, rather, it is curved, showing declining rates of increase over time. The regression that produces a random pattern of residuals (Figure 15) uses year (T), year-squared (T^2), and year-cubed (T^3) as independent variables. The results are:

$$
\begin{array}{llllllll}
(9)\ PRY_t = & 5.993 & + & 0.155T & + & 0.0758T^2 & - & 0.002982T^3 \\
 & (0.309) & & (0.125) & & (0.0136)^{****} & & (0.000426)^{****}
\end{array}
$$

$R^2 = 0.9946$

F-statistic (3,16) = 976.75

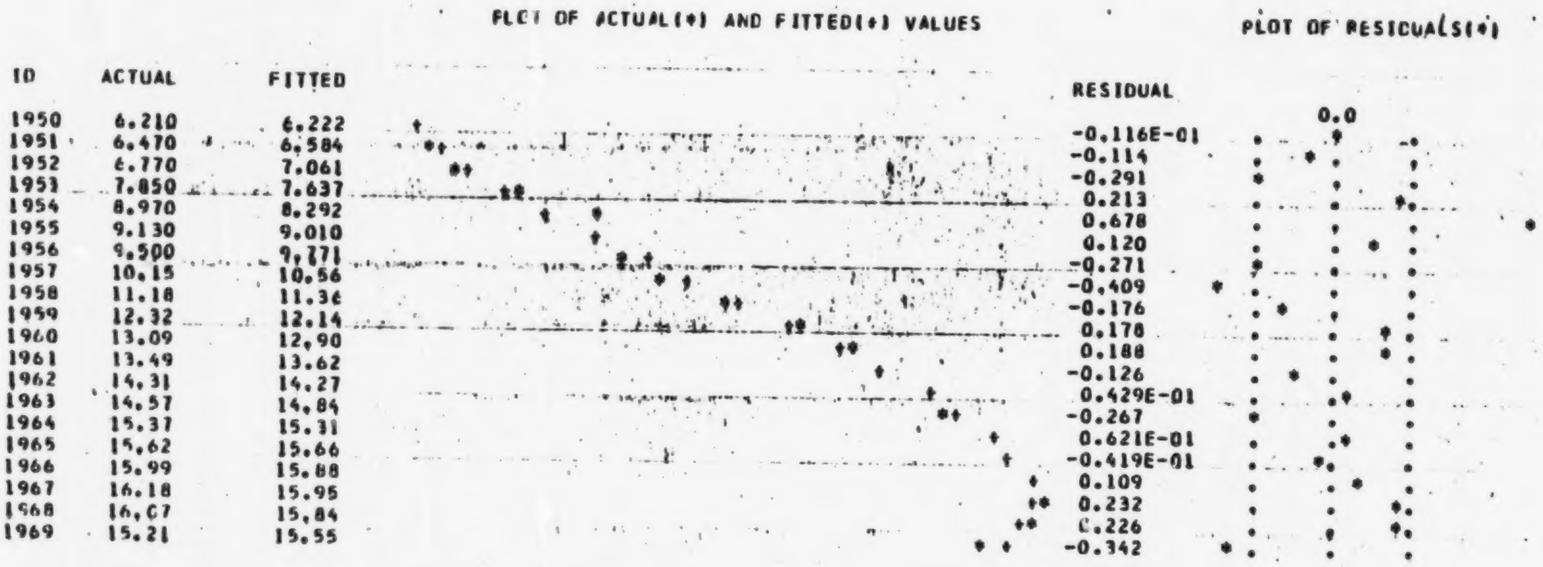
Durbin-Watson statistic = 1.4619

Standard error of the regression = 0.2833

Sum of squared residuals = 1.28433.

This regression explains about 99.5 percent of the variance in productivity through 1969, and autocorrelation is not a problem.

Values of productivity were extrapolated for the years 1970 through 1975 using Equations 8 and 9 (Table 3). The predictions of productivity based on the simple straight line time trend show increasing productivity from 1970 through 1975, as expected, since the slope of the trend is positive before 1967. In 1975, this method predicts productivity levels of around 21.0 tons per man-day, as compared to an actual rate of around 8.6 tons per man-day. The time trend that uses year, year-squared, and year-cubed, which explains around 99.5 percent of the variance of productivity



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                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)
ID      ACTUAL     FITTED                                    RESIDUAL
                                                                             0.0
1950     6.210      6.222                                    -0.116E-01
1951     6.470      6.584                                    -0.114
1952     6.770      7.061                                    -0.291
1953     7.850      7.637                                     0.213
1954     8.970      8.292                                     0.678
1955     9.130      9.010                                     0.120
1956     9.500      9.771                                    -0.271
1957    10.15      10.56                                     -0.409
1958    11.18      11.36                                     -0.176
1959    12.32      12.14                                      0.178
1960    13.09      12.90                                      0.188
1961    13.49      13.62                                     -0.126
1962    14.31      14.27                                      0.429E-01
1963    14.57      14.84                                     -0.267
1964    15.37      15.31                                      0.621E-01
1965    15.62      15.66                                     -0.419E-01
1966    15.99      15.88                                      0.109
1967    16.18      15.95                                      0.232
1968    16.07      15.84                                      0.226
1969    15.21      15.55                                     -0.342
```

Figure 15. Plot for Productivity on Year^1, Year^2, and Year^3, 1950 Through 1969: West Virginia (OLS)

Table 3

Comparison of Predicted Levels of Productivity Based on Time Trends and on Multiple Regressions With Actual Levels of Productivity in West Virginia

	Productivity (tons per man-day)						
Year	Actual	Based on Simple Time Trend (OLS)	Based on T, T^2, T^3 Time Trend (OLS)	Based on AP, ST, CM, DO, and PR (OLS)	Based on AP, CM, DO, and PR (OLS)	Based on AP, ST, CM, and DO (CORC)	Based on AP, CM, and DO (CORC)
1970	13.50	18.04 (±1.81)	15.05 (±0.89)	17.23 (±1.21)	17.12 (±1.24)	15.56 (±2.17)	15.50 (±1.51)
1971	10.74	18.62 (±1.84)	14.33 (±1.11)	13.66 (±1.87)	13.43 (±1.90)	16.21 (±2.36)	16.24 (±1.80)
1972	11.03	19.20 (±1.87)	13.37 (±1.40)	10.83 (±2.66)	10.90 (±2.74)	16.05 (±2.66)	16.16 (±2.10)
1973	10.70	19.78 (±1.90)	12.14 (±1.78)	9.75 (±3.05)	9.96 (±3.13)	16.13 (±2.87)	16.32 (±2.20)
1974	10.20	20.37 (±1.92)	10.64 (±2.24)	-12.04 (±10.58)	-12.54 (±10.90)	16.73 (±2.95)	16.85 (±2.39)
1975	8.58	20.95 (±1.95)	8.84 (±2.79)	-12.48 (±11.03)	-13.16 (±11.34)	17.12 (±2.36)	17.19 (±1.74)

Note: Prediction intervals for a 95.0 percent confidence level are given in parentheses.

from 1950 to 1969, results in predictions for productivity that are greater than actual rates, but not by much in 1974 and 1975--10.64 versus 10.20 in 1974 and 8.84 versus 8.58 in 1975. The actual values fall within the prediction intervals for 1974 and 1975.

Similarly, a regression was run for 1950 through 1969 with productivity as a function of average production, weighted-average seam thickness, percent mined by continuous miners, weighted-average days in operation, and price. The results of the OLS regression are:

$$(10)\ PRY_t = \underset{(14.8836)}{26.7306} - \underset{(5.67487)*****}{21.7237AP_t} + \underset{(0.202678)\#}{0.300416ST_t}$$

$$+ \underset{(0.0240734)}{0.00922351CM_t} - \underset{(0.0142896)*}{0.0255559DO_t} - \underset{(0.118922)\#\#\#\#\#}{0.722419PR_t}$$

$R^2 = 0.9880$

F-statistic (5,14) = 230.212

Durbin-Watson statistic = 1.6977

Standard error of the regression = 0.450545

Sum of squared residuals = 2.84187.

Average production has an unexpected negative coefficient that is significant at the 99.5 percent confidence level. The coefficient of weighted-average seam thickness has the expected positive sign and is significant at the 90.0 percent confidence level. Weighted-average days in operation has an unexpected negative coefficient, significant at a 90.0 percent confidence level. The coefficient of price is negative and highly significant (99.5 percent confidence level). The coefficient of percent mined by continuous miners is not significant. The equation is significant at the 99.0 percent confidence level, and the percent of variance explained is 98.8. The Durbin-Watson statistic falls in the inconclusive region, but the Hart-von Neumann test indicates there is no autocorrelation. The pairwise correlation matrix is presented in Table 4. There is very high negative correlation between the price of coal and percent of coal mined by continuous miners (-0.94). This is not surprising, because both variables have rather strong overall trends (decreasing and increasing, respectively) from 1950 to 1969 and because the increased use of continuous miners lowered costs. Otherwise, no high pairwise correlations appear. A plot of actual and fitted values and a plot of the residuals are presented in Figure 16. The residuals plot gives no indication of heteroskedasticity.

Eliminating ST for the reason explained in the previous section, the results of the OLS regression are:

$$
\begin{array}{llll}
(11)\ PRY_t = & 46.3717 & -\ 17.002AP_t & +\ 0.0223863CM_t \\
 & (7.04265) & (4.88001)^{****} & (0.0232512) \\
 & & & \\
 & -0.0327131DO_t & -\ 0.742348PR_t & \\
 & (0.0139753)^{**} & (0.122784)\text{\#\#\#\#\#} &
\end{array}
$$

$R^2 = 0.9861$

F-statistic (4,15) = 265.991

Durbin-Watson statistic = 1.5594

Standard error of the regression = 0.468175

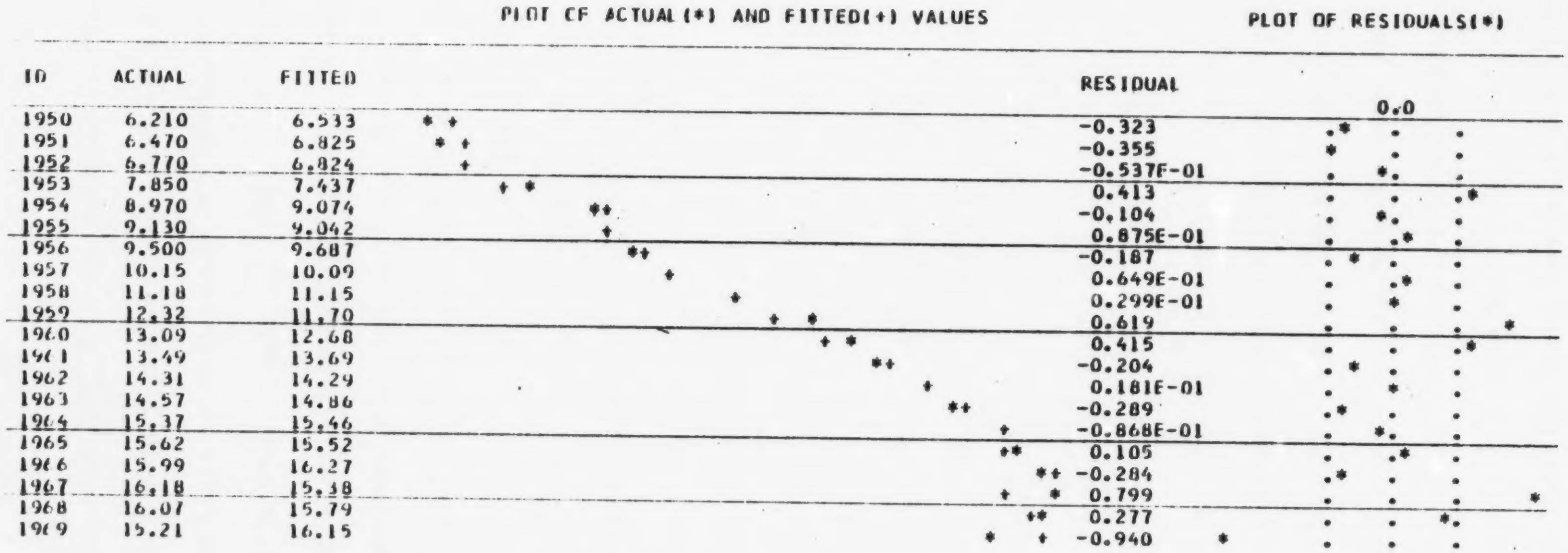
Sum of squared residuals = 3.28782.

Coefficients of AP, DO, and PR are significant at the 99.0, 95.0, and 99.5 percent confidence levels, respectively; however, only PR has the expected sign. Percent mined by continuous miners is not significant but has the expected sign. Over 98.0 percent of the

Table 4

Pairwise Correlation Matrix for AP, ST, CM, DO, and PR:
West Virginia (1950 Through 1969)

	AP	ST	CM	DO	PR
AP	1.0000	-0.20131	-0.69855	0.026747	0.52845
ST	-0.20131	1.0001	0.67478	0.34061	-0.68394
CM	-0.69855	0.67478	1.0000	0.46480	-0.94260
DO	0.026747	0. 4061	0.46480	1.0000	-0.65024
PR	0.52845	-0 .8394	-0.94260	-0.65024	1.0000



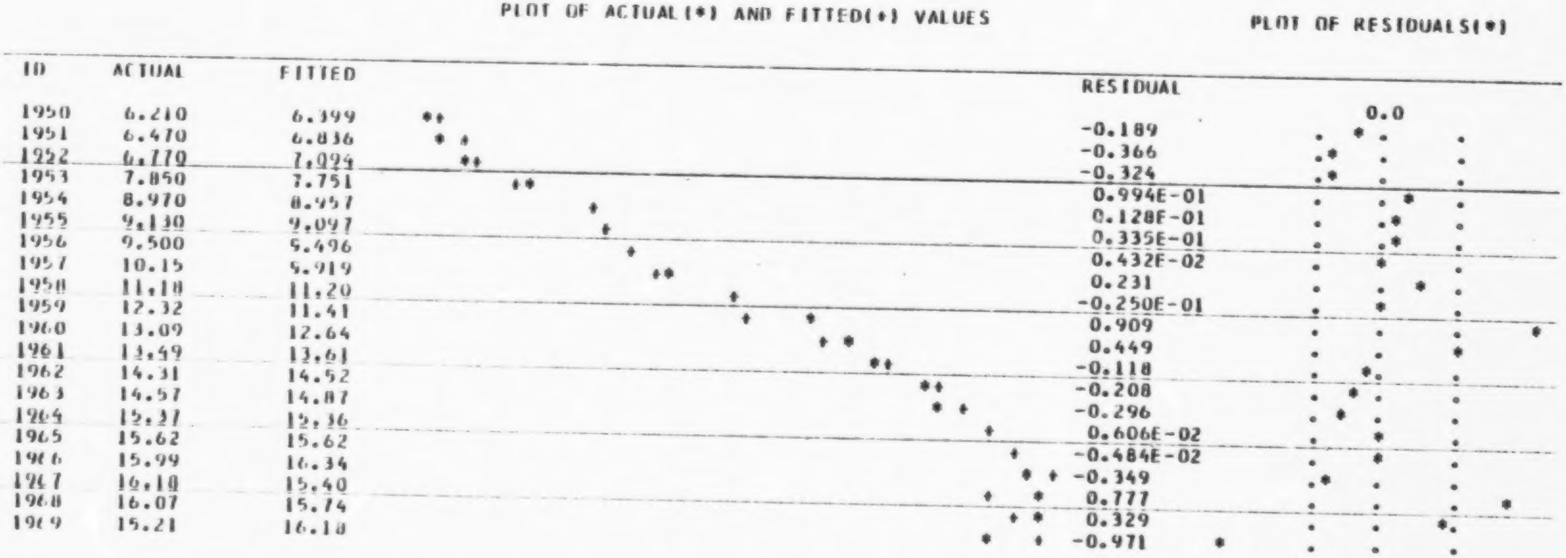
```
                                 PLOT CF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)

ID      ACTUAL        FITTED                                          RESIDUAL
                                                                                           0.0
1950     6.210         6.533                                          -0.323
1951     6.470         6.825                                          -0.355
1952     6.770         6.824                                          -0.537F-01
1953     7.850         7.437                                           0.413
1954     8.970         9.074                                          -0.104
1955     9.130         9.042                                           0.875E-01
1956     9.500         9.687                                          -0.187
1957    10.15         10.09                                            0.649E-01
1958    11.18         11.15                                            0.299E-01
1959    12.32         11.70                                            0.619
1960    13.09         12.68                                            0.415
1961    13.49         13.69                                           -0.204
1962    14.31         14.29                                            0.181E-01
1963    14.57         14.86                                           -0.289
1964    15.37         15.46                                           -0.868E-01
1965    15.62         15.52                                            0.105
1966    15.99         16.27                                           -0.284
1967    16.18         15.38                                            0.799
1968    16.07         15.79                                            0.277
1969    15.21         16.15                                           -0.940
```

Figure 16. Plots for Productivity Model, 1950 Through 1969: West Virginia (OLS)

variance is explained, and the equation is significant at the 99.0 percent confidence level. The Durbin-Watson test is inconclusive; however, the Hart-von Neumann statistic indicates no autocorrelation. Plots of residuals and actual and fitted values are shown in Figure 17 . The residuals plot shows no evidence of heteroskedasticity. The hypothesis that the coefficient of ST equals zero cannot be rejected, since the appropriate F-statistic is 2.20, less than the critical F-value$_{(1,14;\ 0.05)}$ of 4.60.

Values of productivity were extrapolated for 1970 through 1975 using actual values of the independent variables in Equations 10 and 11. These are reported in Table 3 . The predicted values for 1970 and 1971 are greater than actual values at the 95.0 percent confidence level. For 1972 and 1973, within the 95.0 percent confidence limits, the predictions do not differ from the actual levels of productivity; the predictions are lower than actual values in these years. In 1974 and 1975, predicted productivities are negative. This impossible result appears to be due to the fact that the price of coal, which has a negative, highly significant coefficient, was at levels in these two years that greatly exceeded any prices observed in other years covered by the analysis. These high prices force the predicted values for productivity to be negative.

To attempt to eliminate this problem, a regression was made eliminating the price variable for 1950 through 1969, and projections were made based on this equation. Obviously, this method for prediction will result in overall higher values for productivity, since the strong negative influence of price is lost. The results of the OLS regression follow.



```
                         PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)

ID      ACTUAL        FITTED
                                                           RESIDUAL
1950     6.210         6.399                                                     0.0
1951     6.470         6.836                               -0.189
1952     6.770         7.094                               -0.366
1953     7.850         7.751                               -0.324
1954     8.970         8.957                                0.994E-01
1955     9.130         9.097                                0.128E-01
1956     9.500         9.496                                0.335E-01
1957    10.15          9.919                                0.432E-02
1958    11.18         11.20                                 0.231
1959    12.32         11.41                                -0.250E-01
1960    13.09         12.64                                 0.909
1961    13.49         13.61                                 0.449
1962    14.31         14.52                                -0.118
1963    14.57         14.87                                -0.208
1964    15.37         15.36                                -0.296
1965    15.62         15.62                                 0.606E-02
1966    15.99         16.34                                -0.484E-02
1967    16.18         15.40                                -0.349
1968    16.07         15.74                                 0.777
1969    15.21         16.18                                 0.329
                                                           -0.971
```

Figure 17. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1969: West Virginia (OLS)

$$(12)\ PRY_t = \underset{(23.1827)}{21.5431} - \underset{(10.3453)}{16.7663AP_t} + \underset{(0.370969)}{0.439610ST_t}$$

$$+ \underset{(0.0269741)}{0.125300CM_t}\ \text{\#\#\#\#\#}\ + \underset{(0.0211582)}{0.0260871DO_t}$$

$R^2 = 0.9563$

F-statistic (4,15) = 82.0806

Durbin-Watson statistic = 0.6336

Standard error of the regression = 0.829968

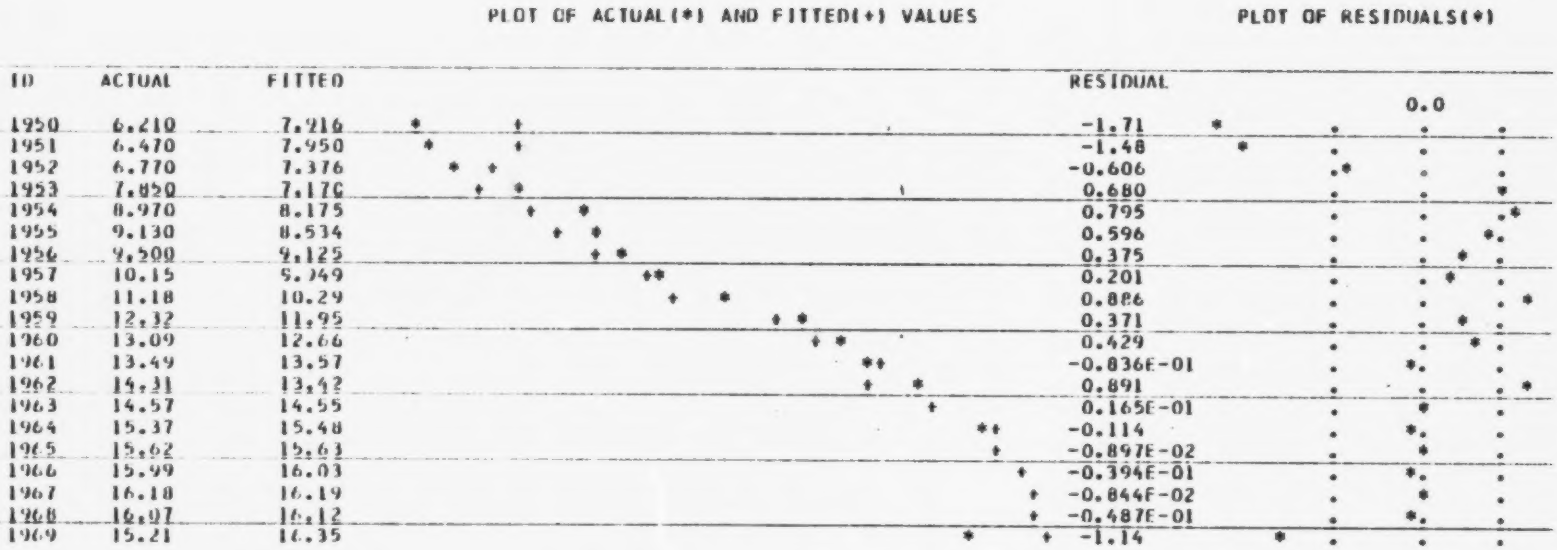
Sum of squared residuals = 10.3327.

The only significant variable is percent of coal mined by continuous miners (99.5 percent confidence level). (Recall that this variable is very highly correlated with price for the years 1950 through 1969.) The signs of all coefficients are as expected except for average production which is negative as in Equations 10 and 11. The F-statistic indicates the equation is significant (99.0 percent confidence level), and the percent of variance explained is over 95.0. The Durbin-Watson statistic indicates significant positive autocorrelation (99.0 percent confidence level). No serious pair-wise correlation arises between independent variables, since price has been eliminated. Plots of actual and predicted values and residuals are shown in Figure 18. The residuals plot shows no evidence of heteroskedasticity.

To correct for autocorrelation, the Cochrane-Orcutt iterative method was used. The results follow.

$$(13)\ PRY_t = \underset{(9.89709)}{3.43204} - \underset{(7.02104)}{10.6964AP_t} + \underset{(0.158975)}{0.131218ST_t}$$

$$+ \underset{(0.0266027)}{0.083463CM_t}\ \text{\#\#\#\#\#}\ + \underset{(0.0102425)}{0.00406535DO_t}$$



ID	ACTUAL	FITTED	RESIDUAL
1950	6.210	7.916	-1.71
1951	6.470	7.950	-1.48
1952	6.770	7.376	-0.606
1953	7.850	7.170	0.680
1954	8.970	8.175	0.795
1955	9.130	8.534	0.596
1956	9.500	9.125	0.375
1957	10.15	9.949	0.201
1958	11.18	10.29	0.886
1959	12.32	11.95	0.371
1960	13.09	12.66	0.429
1961	13.49	13.57	-0.836E-01
1962	14.31	13.42	0.891
1963	14.57	14.55	0.165E-01
1964	15.37	15.48	-0.114
1965	15.62	15.63	-0.897E-02
1966	15.99	16.03	-0.394E-01
1967	16.18	16.19	-0.844F-02
1968	16.07	16.12	-0.487E-01
1969	15.21	16.35	-1.14

Figure 18. Plots for Productivity Model Excluding Price, 1950 Through 1969: West Virginia (OLS)

$R^2 = 0.9874$

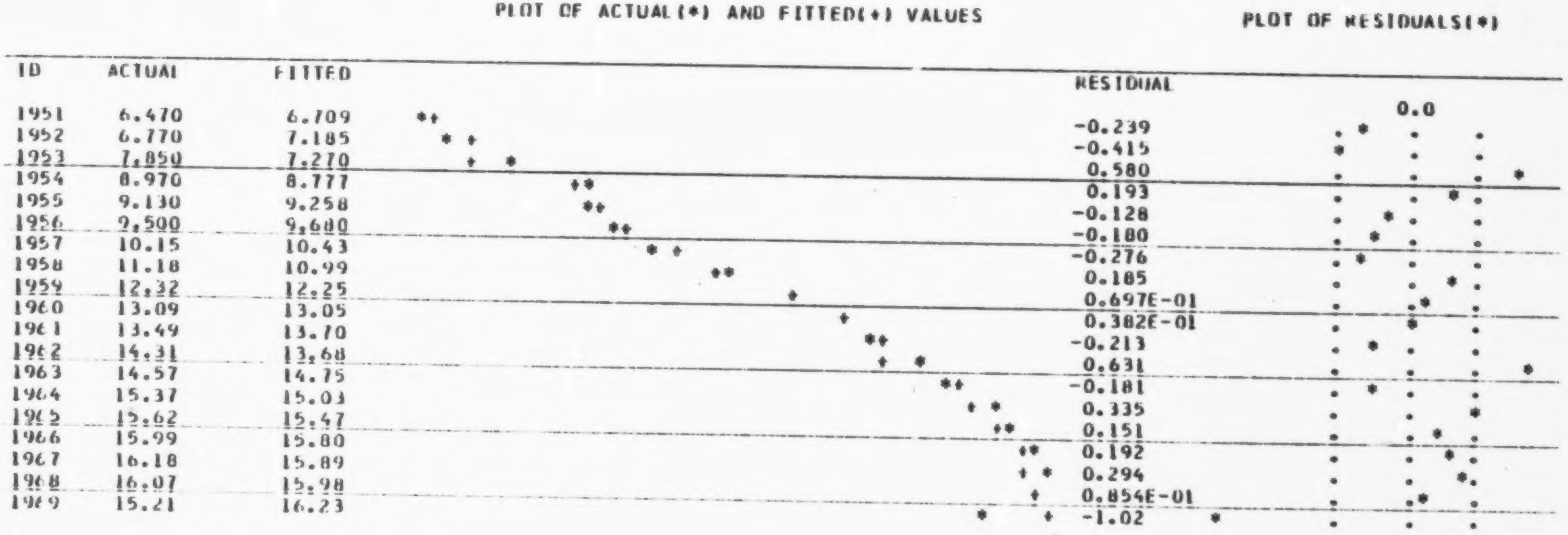
F-statistic (4,14) = 274.500

Durbin-Watson statistic = 1.7749

Standard error of the regression = 0.426364

Sum of squared residuals = 2.54500.

Percent of coal mined by continuous miners is significant at the 99.5 percent confidence level and has the expected positive sign. Coefficients of the other variables are not significant; all except average production have the expected sign. The equation is significant at the 99.0 percent confidence level, and the percent of variance explained is almost 99.0. The Durbin-Watson statistic falls in the inconclusive region, but the Hart-von Neumann statistic indicates there is no autocorrelation. The residuals and actual and fitted values are plotted in Figure 19. The residuals plot shows no evidence of heteroskedasticity. If the full model results of the Cochrane-Orcutt method of regression (not reported) are compared with those of the reduced model (without price) of Equation 12, one may determine whether, according to the Cochrane-Orcutt equations, the exclusion of price is a significant problem for the years 1950 through 1969. The sum of squared errors for the full model is 2.38, with 13 degrees of freedom. The sum of squared errors for the reduced model (Equation 13) is 2.545 with 14 degrees of freedom. The appropriate F*-statistic, 0.9, is less than the critical $F_{(1,13;\ 0.05)}$-value of 4.67, indicating that the elimination of price does not seriously weaken the model in this specific case. This appears to happen because percent of coal mined by continuous miners (CM) becomes a significant influence when



```
                                 PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                          RESIDUAL
                                                                                                0.0
1951    6.470       6.709                                           -0.239
1952    6.770       7.185                                           -0.415
1953    7.850       7.270                                            0.580
1954    8.970       8.777                                            0.193
1955    9.130       9.258                                           -0.128
1956    9.500       9.680                                           -0.180
1957    10.15       10.43                                           -0.276
1958    11.18       10.99                                            0.185
1959    12.32       12.25                                            0.697E-01
1960    13.09       13.05                                            0.382E-01
1961    13.49       13.70                                           -0.213
1962    14.31       13.68                                            0.631
1963    14.57       14.75                                           -0.181
1964    15.37       15.03                                            0.335
1965    15.62       15.47                                            0.151
1966    15.99       15.80                                            0.192
1967    16.18       15.89                                            0.294
1968    16.07       15.98                                            0.854E-01
1969    15.21       16.23                                           -1.02
```

Figure 19. Plots for Productivity Model Excluding Price, 1950 Through 1969: West Virginia (CORC)

price is not used in the regression. This is possibly due to the high correlation (-0.94) between these variables.

Eliminating ST, the results are:

$$(14)\quad PRY_t = \underset{(3.64147)}{5.59665} - \underset{(8.47686)}{9.56401AP_t} + \underset{(0.0177870)\#\#\#\#\#}{0.149557CM_t}$$

$$+ \underset{(0.0201560)}{0.0175898DO_t}$$

$R^2 = 0.9522$

F-statistic (3,16) = 106.287

Durbin-Watson statistic = 0.4708

Standard error of the regression = 0.840388

Sum of squared residuals = 11.3000

Only the coefficient of CM is significant (99.5 percent confidence level), and the sign is correct. The sign of the coefficient of AP is unexpected, but not significant. The percent of variance explained is over 95.0, and the equation is significant at the 99.0 percent confidence level. The Durbin-Watson statistic indicates positive autocorrelation (99.0 percent confidence level). Appropriate plots are shown in Figure 20; the residuals plot gives no indication of the presence of heteroskedasticity.

The results of the Cochrane-Orcutt iteration are:

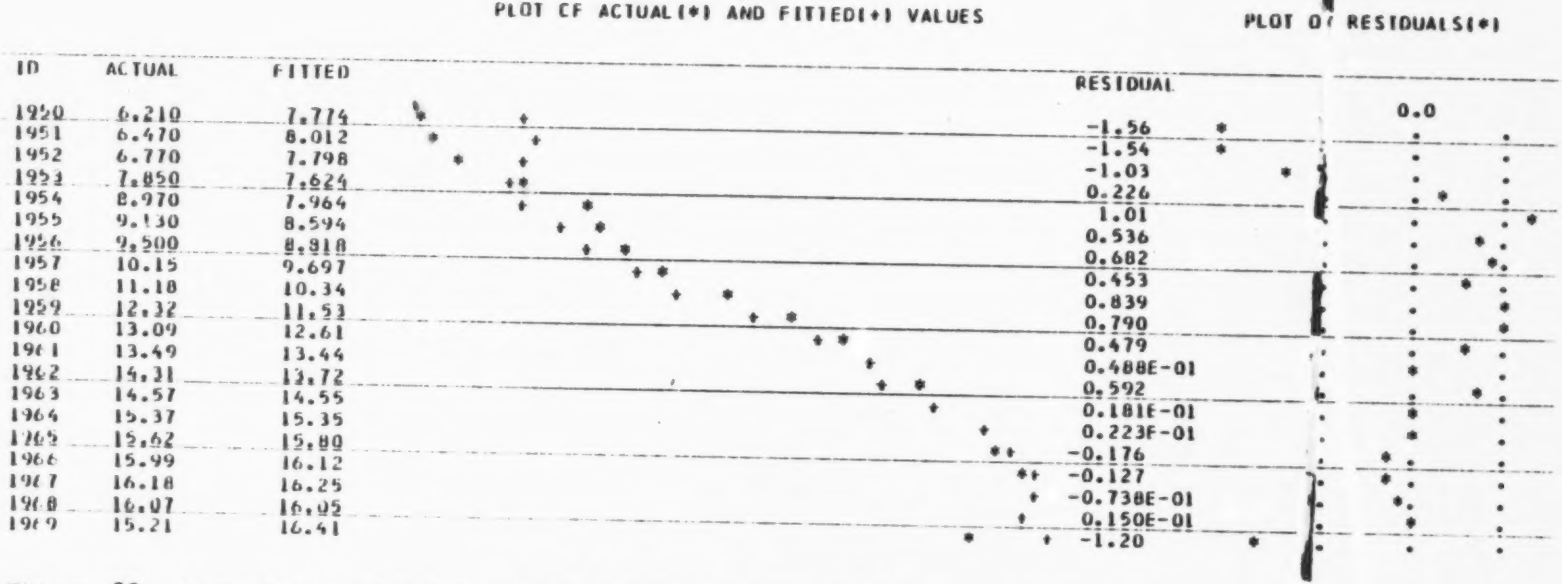
$$(15)\quad PRY_t = \underset{(2.13801)}{11.5291} - \underset{(6.56660)}{8.73801AP_t} + \underset{(0.0249782)\#\#\#\#\#}{0.0895631CM_t}$$

$$+ \underset{(0.00980233)}{0.00197278DO_t}$$

$R^2 = 0.9868$

F-statistic (3,15) = 374.402

Durbin-Watson statistic = 1.6910



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                    PLOT CF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)
ID      ACTUAL      FITTED                                 RESIDUAL
1950    6.210       7.774                                  -1.56
1951    6.470       8.012                                  -1.54
1952    6.770       7.798                                  -1.03
1953    7.850       7.624                                   0.226
1954    8.970       7.964                                   1.01
1955    9.130       8.594                                   0.536
1956    9.500       8.918                                   0.682
1957    10.15       9.697                                   0.453
1958    11.18       10.34                                   0.839
1959    12.32       11.53                                   0.790
1960    13.09       12.61                                   0.479
1961    13.49       13.44                                   0.488E-01
1962    14.31       13.72                                   0.592
1963    14.57       14.55                                   0.181E-01
1964    15.37       15.35                                   0.223F-01
1965    15.62       15.80                                  -0.176
1966    15.99       16.12                                  -0.127
1967    16.18       16.25                                  -0.738E-01
1968    16.07       16.05                                   0.150E-01
1969    15.21       16.41                                  -1.20
                                                                          0.0
```

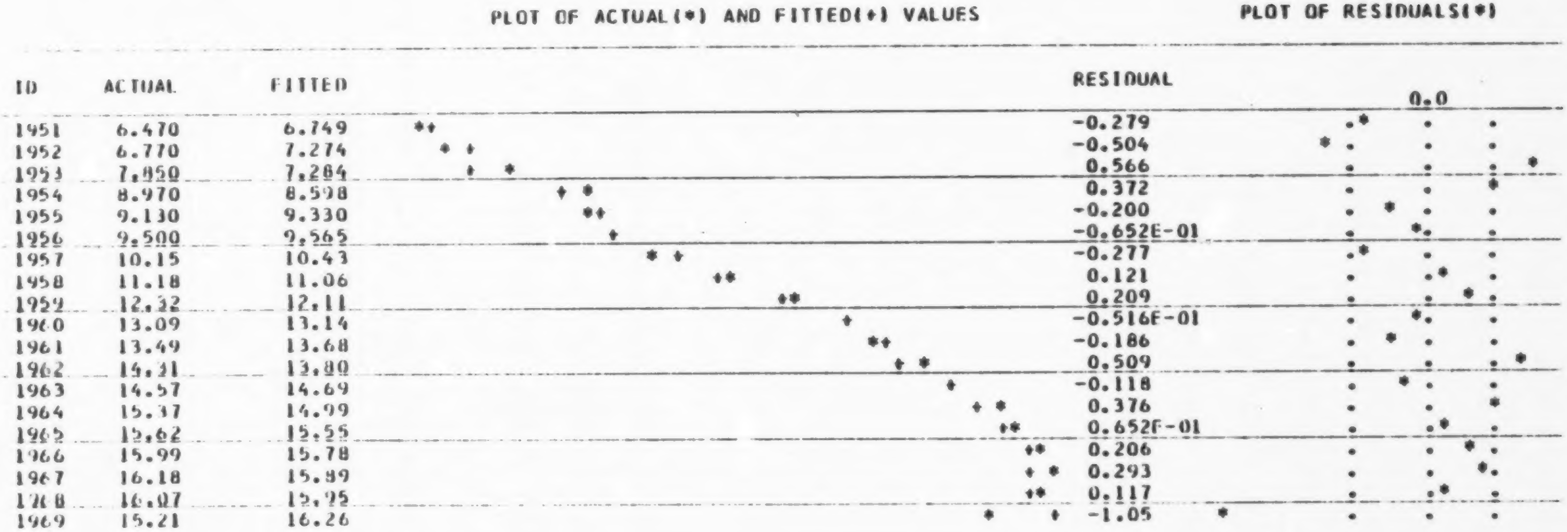
Figure 20. Plots for Productivity Model Excluding Seam Thickness and Price, 1950 Through 196): West Virginia (OLS)

Standard error of the regression = 0.421427

Sum of squared residuals = 2.66401.

The significance results are the same as those for Equation 14. The percent of variance explained is over 98.0, and the equation is significant at the 99.0 percent confidence level. The Durbin-Watson test indicates no autocorrelation. Appropriate plots are shown in Figure 21. The F-statistic for testing the hypothesis that the coefficient of ST equals zero is $0.65_{(1,14)}$; thus, the hypothesis cannot be rejected.

Predictions of productivity using Equations 13 and 15 are presented in Table 3 . These values are less than those predicted by the straight-line time trend, but the prediction intervals overlap. The mean predictions are higher than those based on the complex time trend, but in 1970 through 1973 the differences are insignificant. Thus, given the band of uncertainty about the estimates, the true value of the 1970 estimate by the time trend method could be as high as 15.94 tons which would fall within the plausible range of up to 17 tons implied by Equation 15. Except for 1970, the mean predictions are greater than those based on the regression with price; however, in 1970 and 1971, the differences are not significant. Except for 1970, the predicted values are significantly higher than actual values (95.0 percent confidence level). Since these equations have price omitted from them (and thus a specification error), they may predict productivity levels that are somewhat biased upward. On the other hand, the predictions using price are biased downward, at least in 1974 and 1975.



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                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                               RESIDUAL
                                                                              0.0
1951    6.470       6.749                                -0.279
1952    6.770       7.274                                -0.504
1953    7.850       7.284                                 0.566
1954    8.970       8.598                                 0.372
1955    9.130       9.330                                -0.200
1956    9.500       9.565                                -0.652E-01
1957    10.15       10.43                                -0.277
1958    11.18       11.06                                 0.121
1959    12.32       12.11                                 0.209
1960    13.09       13.14                                -0.516E-01
1961    13.49       13.68                                -0.186
1962    14.31       13.80                                 0.509
1963    14.57       14.69                                -0.118
1964    15.37       14.99                                 0.376
1965    15.62       15.55                                 0.652E-01
1966    15.99       15.78                                 0.206
1967    16.18       15.89                                 0.293
1968    16.07       15.95                                 0.117
1969    15.21       16.26                                -1.05
```

Figure 21. Plots for Productivity Model Excluding Seam Thickness and Price, 1950 Through 1969: West Virginia (CORC)

Using the results of the model for 1950 through 1975, predictions of productivity without the Mine Act were made by adding the amount of productivity lost due to the Mine Act to the prediction of productivity. These predictions, shown in Table 5 , are for productivities that are greater than actual productivities and that have an overall declining trend. The prediction for 1975 is 12.74 tons per man-day. For comparison, the loss in productivity due to the change in price is also shown in Table 5 . These results show that the Mine Act had a greater effect on productivity losses than the rising price of coal. Percentage losses in productivity due to MACT are shown in Table 6 . The results indicate that productivity was down due to the Mine Act by around 21.8 percent in 1975.

Summary

Some of the results of the regressions are summarized in Tables 7 and 8 . The relationships of the independent variables to productivity in the model using data for 1950 through 1975 may be summarized as follows:

(1) average production is negatively related, significant in PLS equations, and not significant in Cochrane-Orcutt equations;

(2) weighted-average seam thickness is negative and not significant;

(3) percent mined by continuous miners is positive if significant and negative if not significant;

(4) weighted-average days in operation is not significant;

Table 5

Effect of MACT and PR on Productivity: West Virginia*

					Tons Per Man-Day						
Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Productivity Caused by MACT -((1) x (2))			(4) Prediction of Productivity from Model (95.0 percent confidence level)	(5) Prediction of Productivity Without MACT (4) + (3)			(6) Actual Productivity
		Mean			Low	Mean	High		Low	Mean	High	
1969	-0.178	-0.071	0.035	0				15.69				15.21
1970				5.15924	-0.15	0.37	0.93	14.96	14.81	15.33	15.89	13.50
1971				10.4678	-0.31	0.74	1.88	12.96	12.65	13.70	14.84	10.74
1972				29.2330	-0.88	2.08	5.26	10.48	9.60	12.56	15.74	11.03
1973				42.6833	-1.28	3.03	7.68	11.17	9.89	14.20	18.85	10.70
1974				52.0947	-1.56	3.70	9.38	9.64	8.08	13.34	19.02	10.20
1975				39.1479	-1.17	2.78	9.83	9.96	8.79	12.74	19.79	8.58

				Cents Per Million Btu		Tons Per Man-Day		
Year	(7) 95.0 Percent Confidence Interval for Coefficient of PR			(8) Value of PR	(9) Change in PR From 1969	(10) Reduction in Productivity Caused by Change in PR -((7) x (9))		
		Mean				Low	Mean	High
1969	-0.200	-0.091	0.017	29.6				
1970				27.3	-2.3	0.04	-0.21	-0.46
1971				33.3	3.7	-0.06	0.34	0.74
1972				35.5	5.9	-0.10	0.54	1.18
1973				36.7	7.1	-0.12	0.65	1.42
1974				69.4	39.8	-0.68	3.62	7.96
1975				69.8	40.2	-0.68	3.66	8.04

---

*Using results of Equation 6.

Table 6

Percentage Losses in Productivity Due to the Mine Act in West Virginia

Year	Using Predictions of Regression 6 (data through 1975) (percentage loss)
1970	2.4
1971	5.4
1972	16.6
1973	21.3
1974	27.7
1975	21.8
Average Per Year	15.9

Table 7

Results of Regressions Summary for West Virginia

Equation	Constant	AP	ST	CM	DO	PR	MACT	PC	T(Year)	T^2	T^3	R^2	S	SSR	Autocorrelation (Durbin-Watson Statistic)	F-Statistic
1950 Through 1975																
2(OLS)	13.869	-30.249 *	-0.053	0.088 ##	0.028	-0.090 #	-0.074					0.86	1.36	35.37	+(1.15)	$19.67_{(6,19)}$
3(CORC)	24.080	-12.785	-0.020	-0.070	-0.008	-0.039 #	0.017					0.93	0.94	15.98	+(1.29)	$39.07_{(6,18)}$
4(OLS)	12.616						-0.139 ###	-2.916 ****				0.67	1.91	83.54	+(0.91)	$23.61_{(2,23)}$
5(CORC)	13.842						-0.035	0.485				0.92	0.92	18.77	+(1.09)	$120.36_{(2,22)}$
6(OLS)	10.624	-31.301 ***		0.085 ###	0.029	-0.091 ##	-0.071 #					0.86	1.33	35.38	+(1.15)	$24.83_{(5,20)}$
7(CORC)	22.892	-13.084		-0.071	-0.008	-0.063 #	0.018					0.93	0.92	15.99	+(1.28)	$49.47_{(5,19)}$
1950 Through 1969																
8(OLS)	5.808								0.582 ****			0.95	0.78	11.01	+(0.42)	$368.74_{(1,18)}$
9(OLS)	5.993								0.155	0.076 ****	-0.003 ****	0.99	0.28	1.28	None (1.46)	$976.75_{(3,16)}$
10(OLS)	26.731	-21.724 ****	0.300 #	0.009	-0.026 *	-0.722 ###						0.99	0.45	2.84	None (1.70)	$230.21_{(5,14)}$
11(OLS)	46.372	-17.002 ****		0.002	-0.033 **	-0.742 ###						0.99	0.47	3.29	None (1.56)	$265.99_{(4,15)}$
12(OLS)	-21.543	-16.766	0.440	0.125 ###	0.026							0.96	0.63	10.33	+(0.63)	$82.08_{(4,15)}$
13(CORC)	3.432	-10.696	0.131	0.083 ###	0.004							0.99	0.43	2.55	None (1.77)	$274.50_{(4,14)}$
14(OLS)	5.597	- 9.564		0.150 ###	0.018							0.95	0.84	11.30	+(0.47)	$106.29_{(3,10)}$
15(CORC)	11.529	- 8.738		0.090 ###	0.002							0.99	0.42	2.66	None (1.69)	$374.40_{(3,15)}$

Significance Levels:	
*	Significant at 90.0 percent confidence level (two-tail test)
**	Significant at 95.0 percent confidence level (two-tail test)
***	Significant at 98.0 percent confidence level (two-tail test)
****	Significant at 99.0 percent confidence level (two-tail test)
#	Significant at 90.0 percent confidence level (one-tail test)
##	Significant at 95.0 percent confidence level (one-tail test)
###	Significant at 99.5 percent confidence level (one-tail test)

Table 8

Ninety-five Percent Confidence Intervals for Coefficients in West Virginia Regressions

Equation	AP	ST	CM	DO	PR	MACT	PC	T(Year)	T^2	T^3
					1950 Through 1975					
2(OLS)	-65.15 4.65	-1.26 1.15	-0.19 0.19	-0.04 0.10	-0.20 0.02	-0.20 0.05				
3(CORC)	-44.68 19.11	0.69 0.65	0.22 0.08	-0.05 0.03	-0.15 0.02	-0.08 0.11				
4(OLS)						-0.20-0.08	-3.82 -2.01			
5(CORC)						-0.10 0.03	-0.64 1.61			
6(OLS)	-55.95 -6.66		0.03 0.14	-0.03 0.09	-0.20 0.02	-0.18 0.03				
7(CORC)	-42.41 16.24		-0.21 0.06	-0.05 0.03	-0.85 0.73	-0.07 0.11				
					1950 Through 1969					
8(OLS)								0.52 0.65		
9(OLS)								-0.11 0.42	0.05 0.10	-0.004 -0.002
10(OLS)	-33.89 -9.55	-0.13 0.73	-0.04 0.06	-0.06 0.00	-0.98 -0.47					
11(OLS)	-6.60 -27.40		-0.03 0.07	-0.00-0.06	-1.00 -0.48					
12(OLS)	-38.81 5.28	-0.35 1.23	0.07 0.18	-0.02 0.07						
13(CORC)	-25.80 4.36	0.21 0.47	0.03 0.14	-0.02 0.03						
14(OLS)	-27.53 8.41		0.11 0.19	-0.02 0.06						
15(CORC)	-22.73 5.26		0.04 0.14	0.02 0.02						

(5) price is negative and significant; and

(6) the Mine-Act variable is predominantly negative and generally not significant in the Cochrane-Orcutt regressions.

The regression analyses indicate that the approximate effects of each independent variable on productivity are:

(1) an increase of average production of 0.1 million tons decreases productivity by 1.3 tons per man-day;

(2) an increase in weighted-average seam thickness of 1.0 inch decreases productivity by 0.02 tons per man-day;

(3) an increase in percent of coal mined by continuous miners of 1.0 increases productivity by 0.09 tons per man-day;

(4) an increase in weighted-average days in operation of 10.0 increases productivity by 0.3 tons per man-day;

(5) an increase in the price of coal of 1.0 cent per million Btu decreases productivity by 0.06 tons per man-day; and

(6) an increase in the enforcement of CMHSA as approximated in inspections per mine by 10.0 decreases productivity by 0.02 tons per man-day.

However, the statistical significance of these estimates was not established. The results of these regressions for West Virginia indicate that the Mine Act was responsible for losses in productivity in 1970 through 1975 of approximately 2, 5, 17, 21, 28, and 22 percent, respectively.

Pennsylvania

Data and Trends of Variables

The data used for Pennsylvania are presented in Table 9. The state data on productivity (derived from figures on production, days worked, and employment), average production, seam thickness, and days in operation were obtained from the Pennsylvania Annual Report on Mining, Oil and Gas, and Land Reclamation and Conservation Activities for 1950 through 1975. Other data sources are as given in the section on methods of investigation.

The trend of productivity (tons per man-day) in Pennsylvania for the years 1950 through 1975 is shown in Figure 22. There was a steady increase in output per man-day (OMD) from 1950 (4.9 tons per man-day) through 1968 (15.6 tons per man-day)(Table 9). The overall percentage increase in productivity from 1950 to 1955 was 42.4; from 1955 to 1960 it was even greater: 46.9 percent. However, the rate of increase began to lessen from 1960 to 1965, with an overall increase of 39.4 percent. During 1965 through 1969, the overall increase was only one percent. Significant declines in productivity occurred from 1969 through 1975, with an overall percentage decrease of 42.4 percent. The level of average productivity in 1975 was 8.36 tons per man-day, a figure similar to levels attained in 1958.

Piecewise regression analysis indicates that the change in trend of productivity from positive to negative in 1969 is significant at the 99.0 percent confidence level. Using the piecewise regression model, the results using a join point (α) of 20 (1969) are:

Table 9

Pennsylvania Data

Year	Productivity PRY (tons per man-day)	Average Production AP^a (tons)	Weighted-Average Seam Thickness ST (inches)	Percent Mined by Continuous Miners CM (percent)	Weighted-Average Days in Operation DO	Actual Price of Coal, 1975 dollars PR_A (cents per million Btu)	Price of Coal Under the Assumption of No-Act, 1975 Dollars PR (cents per million Btu)	Number of Inspections Per Mine Under CMHSA MACT
1950	4.93	82429.4	64.72	1.86	200	46.7	46.7	0.0
1951	5.16	100102.0	64.84	2.98	226	46.2	46.2	0.0
1952	5.42	93457.1	64.50	4.78	195	47.4	47.4	0.0
1953	5.89	110314.0	66.90	7.67	219	48.2	48.2	0.0
1954	6.75	97850.0	67.19	14.37	188	46.7	46.7	0.0
1955	7.02	124513.0	67.53	20.28	233	44.4	44.4	0.0
1956	7.39	70767.4	66.24	26.30	224	44.5	44.5	0.0
1957	7.97	73010.1	66.13	33.09	218	46.2	46.2	0.0
1958	8.82	58343.8	64.95	45.58	192	46.8	46.8	0.0
1959	9.72	57866.9	65.30	50.76	184	43.3	43.3	0.0
1960	10.31	62170.4	66.37	61.29	189	41.3	41.3	0.0
1961	10.87	62965.3	65.65	67.28	202	40.4	40.4	0.0
1962	12.33	71971.2	65.49	70.34	201	39.1	39.1	0.0
1963	12.91	79198.6	64.81	71.12	222	37.5	37.5	0.0
1964	13.62	99316.9	64.69	74.71	236	36.0	36.0	0.0
1965	14.37	116872.0	63.70	78.61	236	35.9	35.9	0.0
1966	14.66	138437.0	62.62	80.51	234	35.6	35.6	0.0
1967	15.42	181936.0	62.73	81.15	235	35.1	35.1	0.0
1968	15.59	215099.0	64.19	79.44	228	34.3	34.3	0.0
1969	14.51	247877.0	63.22	80.71	240	36.1	36.1	0.0
1970	13.37	278528.0	63.48	83.27	244	41.1	30.3	0.0
1971	11.75	255648.0	62.85	84.83	208	46.5	34.3	5.15924
1972	10.99	324979.0	63.14	87.51	239	49.6	36.6	10.4678
1973	10.35	356314.0	63.65	90.05	242	53.7	39.6	29.2330
1974	9.64	340657.0	62.66	89.19	227	79.6	58.7	42.6833
1975	8.36	341717.0	61.34	90.77	243	93.7	69.1	39.1479

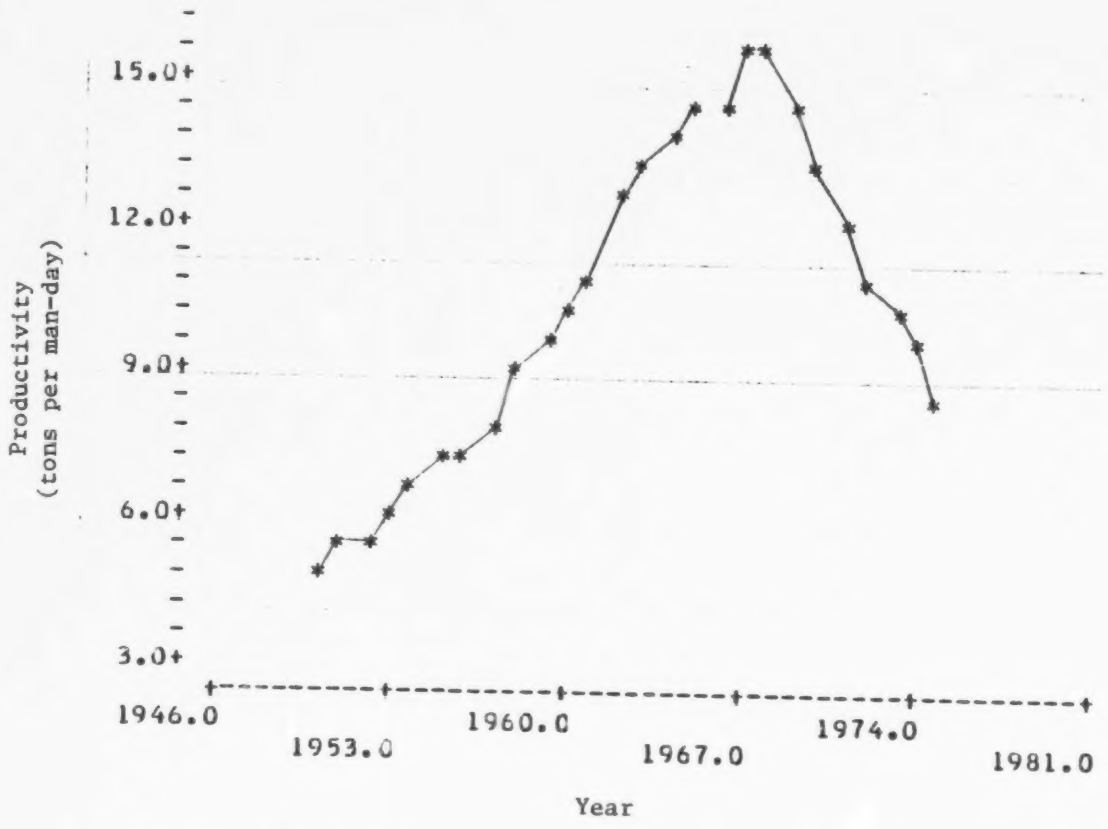


Figure 22. Trend of Productivity in Underground Coal Mines: Pennsylvania (1950 Through 1975)

$$(16)\ PRY_t = \underset{(0.320)}{3.809} + \underset{(0.0255)****}{0.5971\ X_1} - \underset{(0.113)****}{1.929\ X_2\ (X_1-20)}$$

$R^2 = 0.96$

F-statistic (2,23) = 274.50

Standard error of the regression = 0.705

****Significant at the 99.0 percent confidence level.

Since productivity actually reached a peak in 1968, the model was run using join points of 19 (1968) and 20 (1969). The change in trend in 1968 is highly significant (99.0 percent confidence level), while that in 1969 is not significant. Again some other forces than CMHSA may have initiated the decline but the Act probably contributed to the continuation of the fall. The results are:

$$(16A)\ PRY_t = \underset{(0.198)}{3.401} + \underset{(0.0174)****}{0.6554\ X_1} - \underset{(0.345)****}{2.302\ X_2\ (X_1-19)} + \underset{(0.395)}{0.671\ X_3\ (X_1-20)}$$

$R^2 = 0.987$

F-statistic (3,22) = 543.62

Standard error of the regression = 0.414

****Significant at the 99.0 percent confidence level.

Percent of coal mined by continuous miners (Figure 23) shows a strong, increasing trend throughout the time period 1950 to 1975, although most of the gains are before 1965. Although weighted-average seam thickness (Figure 24) varies only slightly over the time period (maximum - 5.6 feet, minimum - 5.1 feet), there is an overall decreasing trend. Weighted-average days in operation (Figure 25) has no strong trend over time; however, there is a slight, positive slope overall. Average

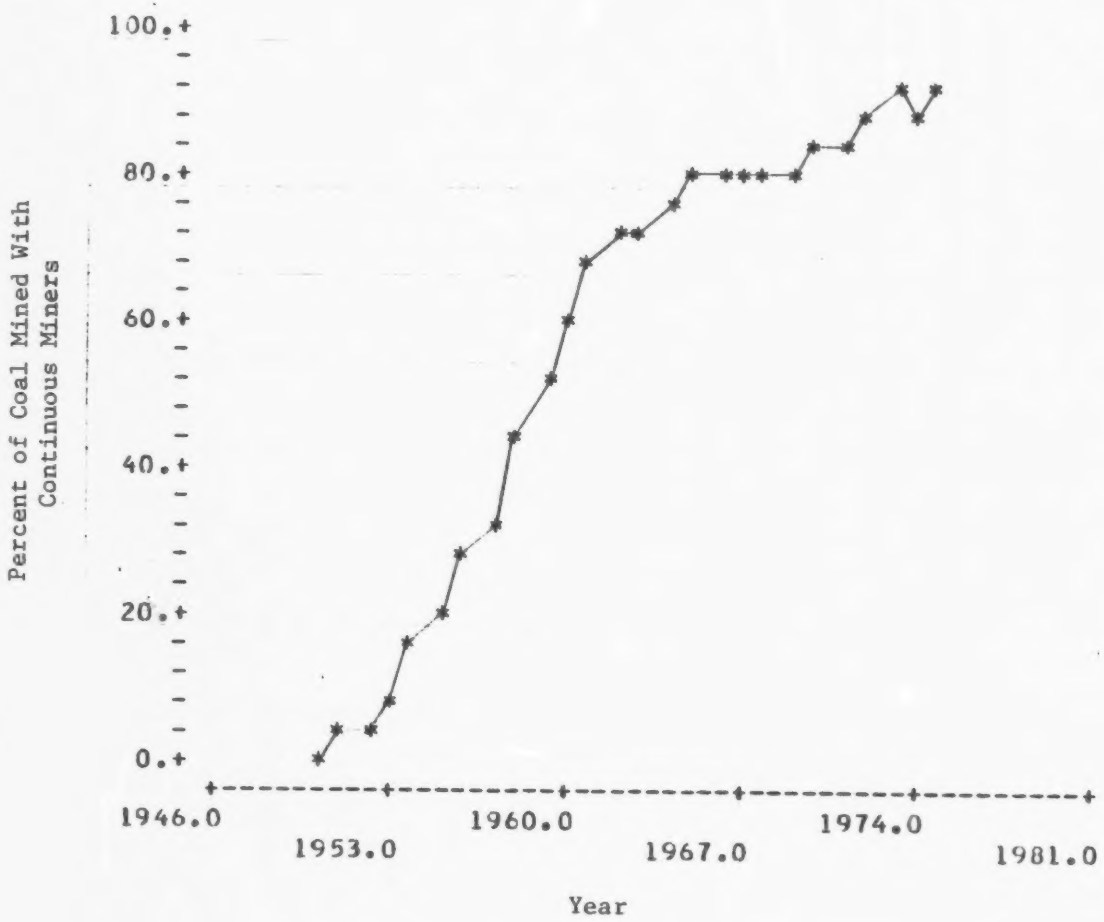


Figure 23. Trend of Percent of Coal Mined With Continuous Miners: Pennsylvania (1950 Through 1975)

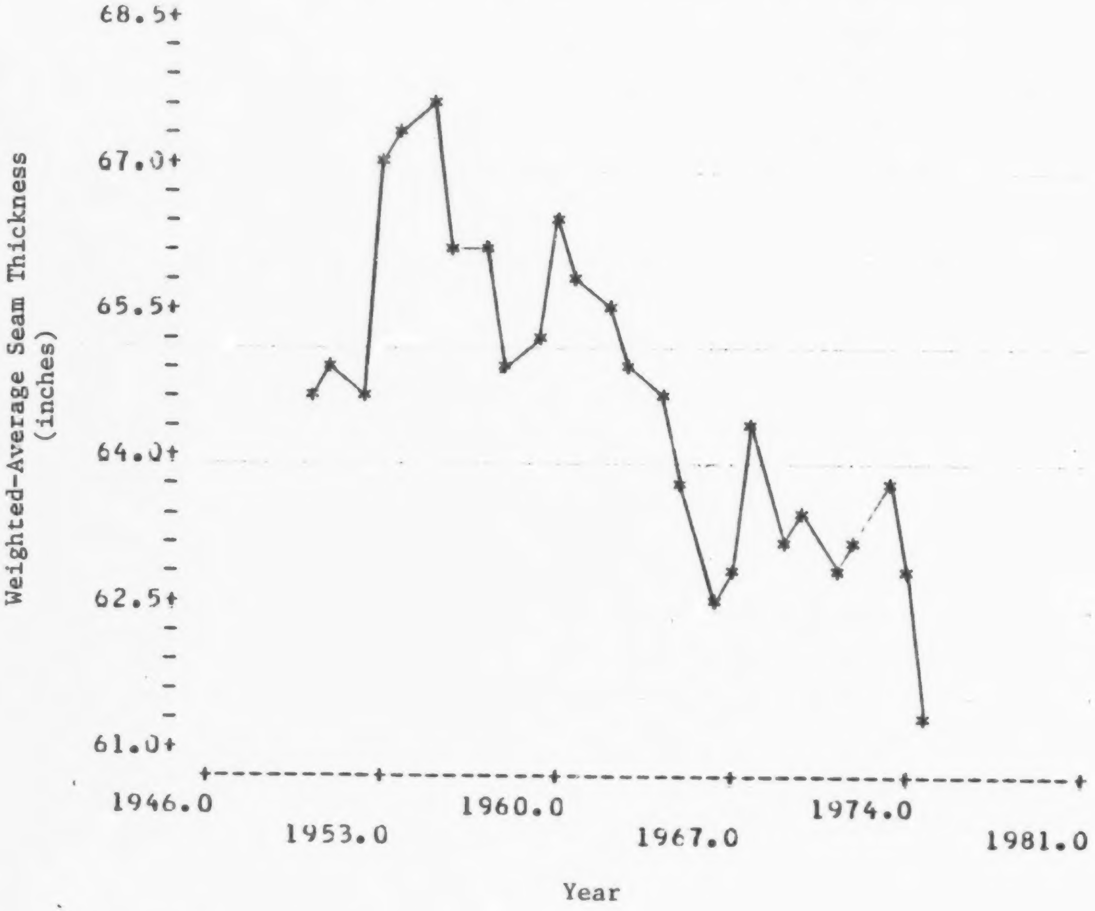


Figure 24. Trend of Weighted-Average Seam Thickness: Pennsylvania (1950 Through 1975)

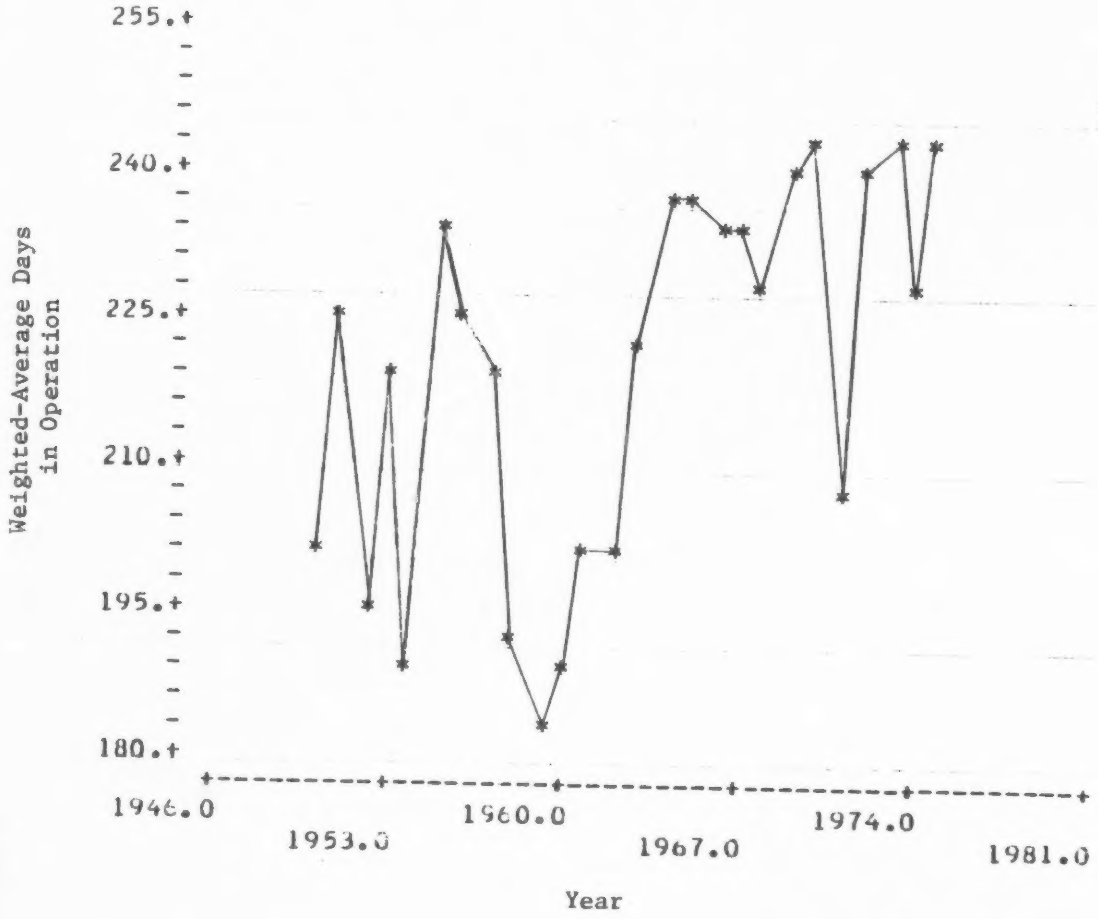


Figure 25. Trend of Weighted-Average Days in Operation: Pennsylvania (1950 Through 1975)

production (Figure 26) has a roughly level to slightly declining trend from 1950 to around 1962, then an overall increasing trend throughout the remaining time period. Using piecewise regression, a break in trend in 1962 is significant at the 99.0 percent confidence level. The actual price of coal in Pennsylvania (Figure 27) shows a gradually declining trend from 1950 to 1969, then an increasing trend through 1975, with the major increase in 1974 and 1975. A break in trend in 1969 is significant at the 99.0 percent confidence level. Under the assumption that there was no Coal Mine Health and Safety Act in the years 1969 through 1975, estimates indicate that the cost of coal would have been around 26.3 percent less (Fettig, 1978, p. 53; see Table 9). The resulting price has essentially the same trend, except that the increases are not so large (Figure 28).

Results of Regressions for 1950 Through 1975

The results for the OLS regression of the model for productivity for the years 1950 through 1975 follow.

$$
\begin{array}{lllll}
(17)\ PRY_t = & 10.4291 & - 0.980847\ AP_t & - 0.105450\ ST & + 0.0989410\ CM_t \\
 & (13.4374) & (4.63736) & (0.185967) & (0.00985610)\#\#\#\#\# \\
 & + 0.0203392\ DO_t & - 0.0598859\ PR_t & - 0.103228\ MACT_t & \\
 & (0.0123793)\# & (0.0354697)\# & (0.0304831)\#\#\#\#\# &
\end{array}
$$

$R^2 = 0.9498$

F-statistic (6,19) = 59.8591

Durbin-Watson statistic = 1.3912

Standard error of the regression = 0.867042

Sum of squared residuals = 14.2835 .

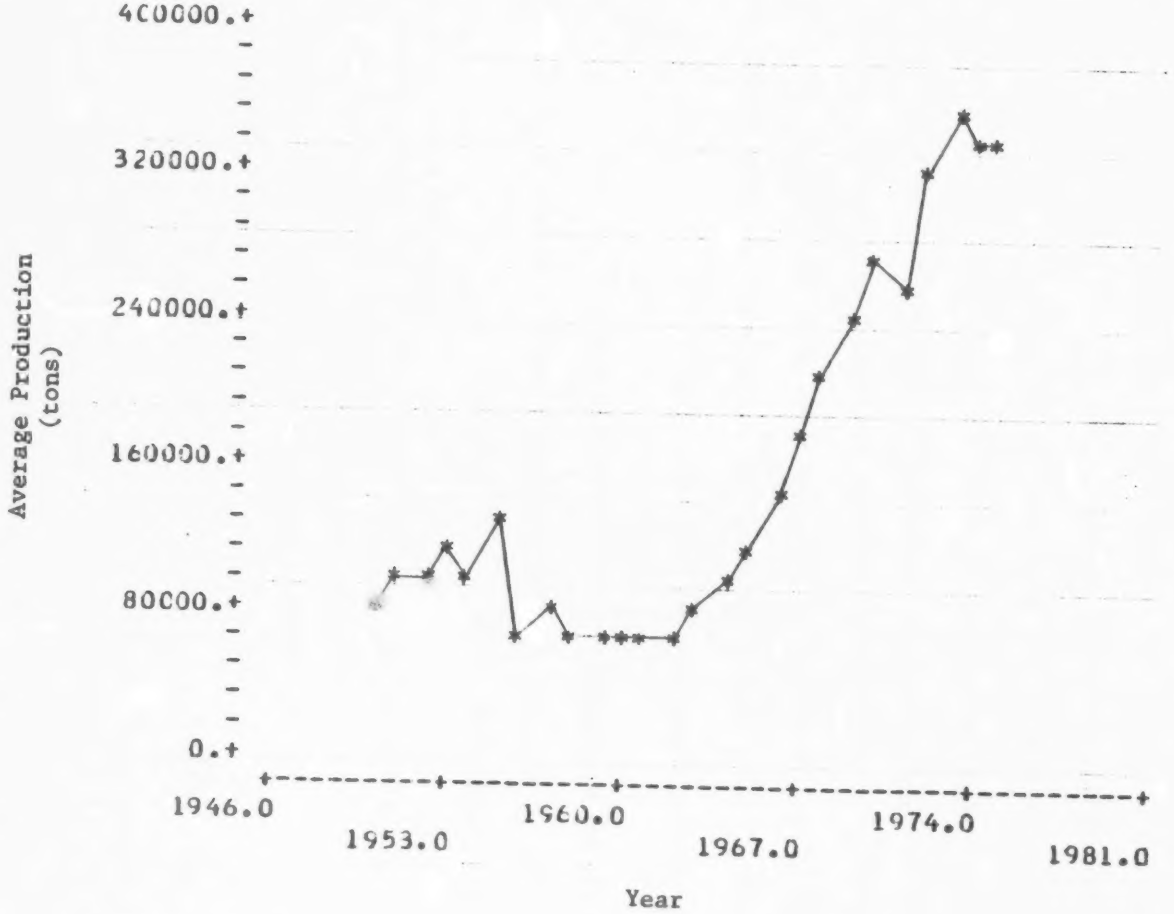


Figure 26. Trend of Average Production: Pennsylvania (1950 Through 1975)

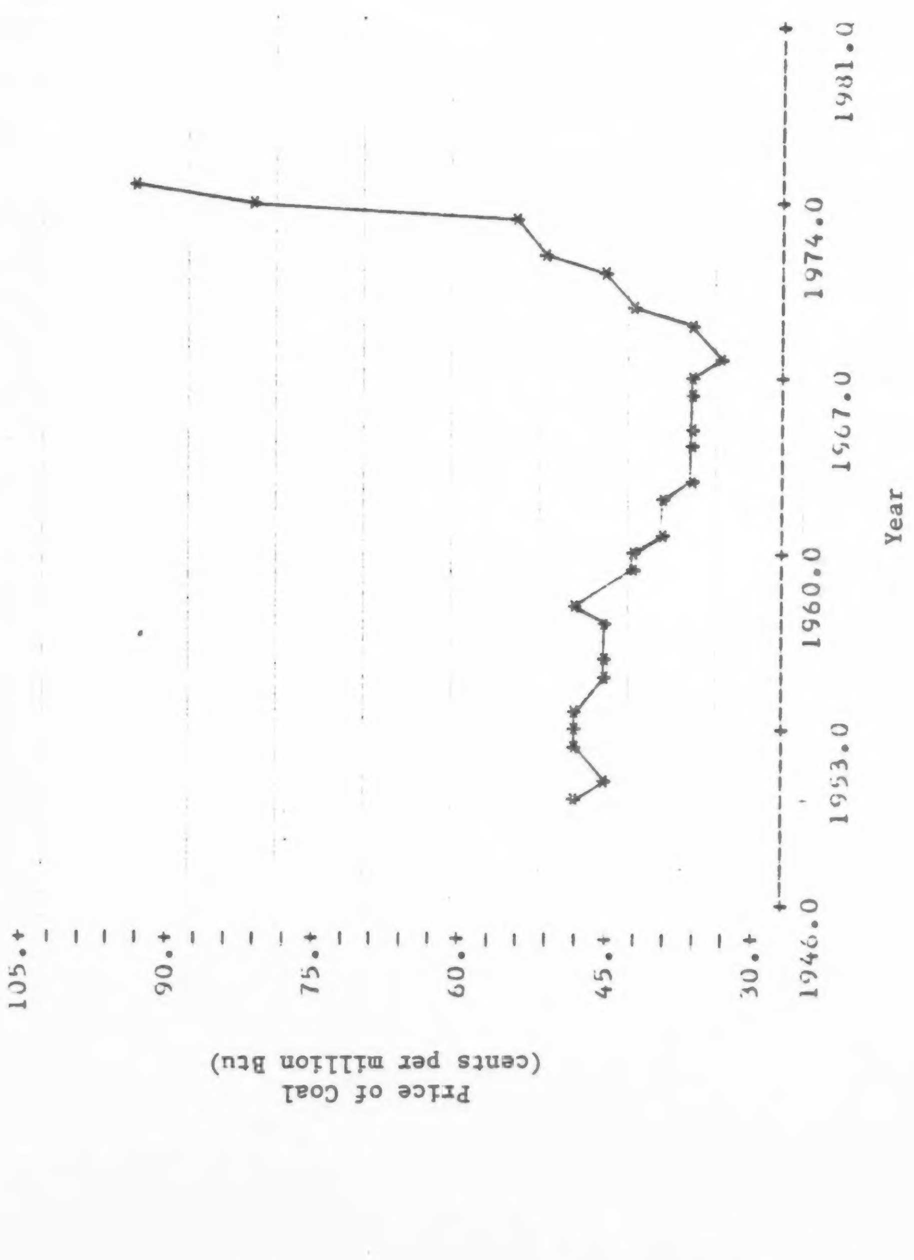


Figure 27. Trend of the Price of Coal: Pennsylvania (1950 Through 1975)

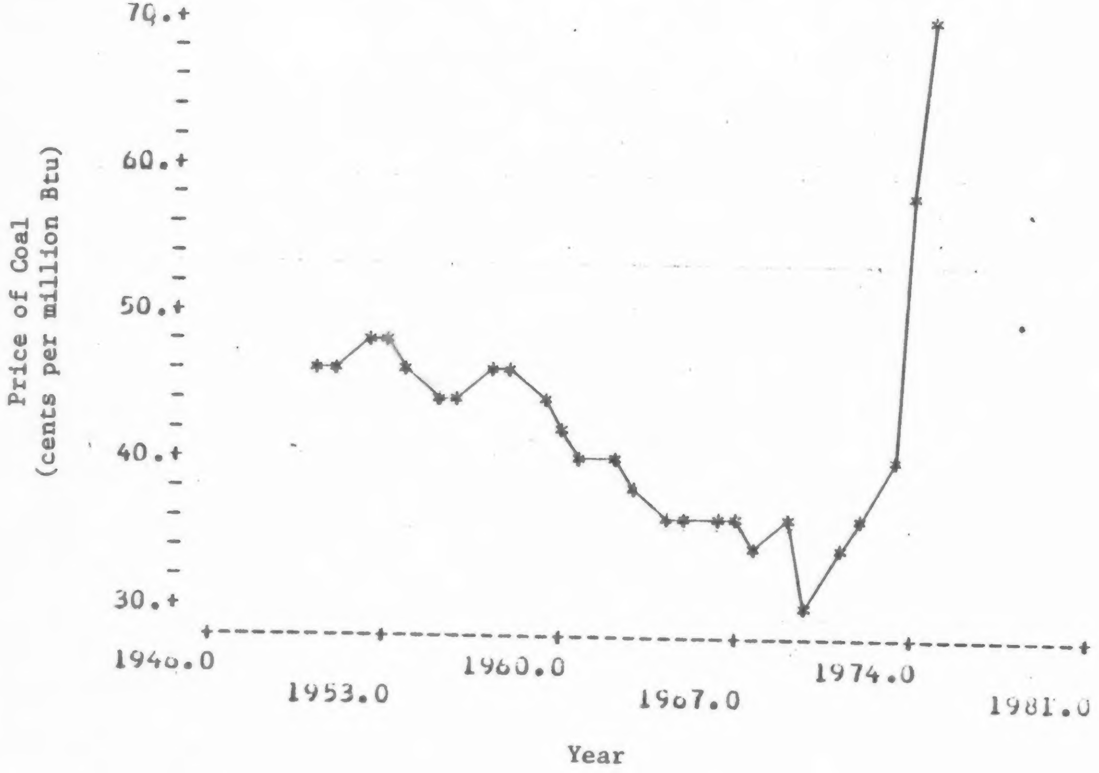


Figure 28. Trend of the Price of Coal Assuming No CMHSA: Pennsylvania (1950 Through 1975)

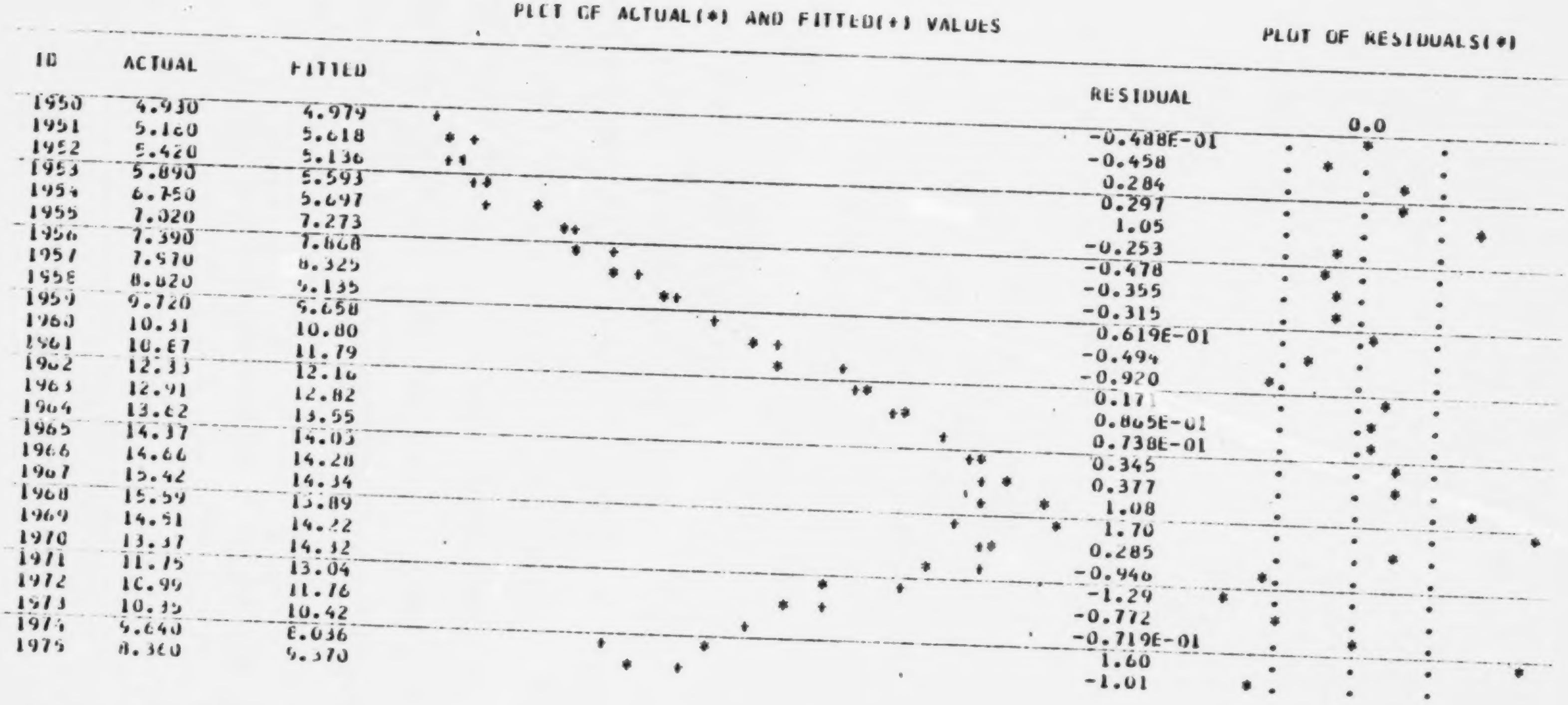
All variables except MACT and PR are expected to have positive coefficients. The coefficients of days in operation (DO) and price (PR) are significant at the 90.0 percent confidence level. The coefficients of percent mined by continuous miners (CM) and the Mine-Act variable (MACT) are significant at the 99.5 percent confidence level. All significant variables have coefficients with the expected sign. Neither AP nor ST are significant at levels of 90.0 percent confidence or greater. The F-statistic indicates that the equation is significant at the 99.0 percent confidence level; almost 95.0 percent of the variance is explained. The Durbin-Watson statistic is the inconclusive region. However, the Hart-von Neumann test indicates positive autocorrelation (95.0 percent confidence level). The pairwise correlation matrix (Table 10) indicates that the greatest correlations are between AP and MACT (0.82) and between AP and ST (-0.72). A plot of actual and fitted values and a plot of the residuals are presented in Figure 29. The residuals plot gives no indication of the presence of heteroskedasticity.

The principal components method was used to correct to multicollinearity. Average production, weighted-average seam thickness, percent mined by continuous miners, weighted-average days in operation, and price were combined into one variable, PC. The factor loadings for the principal component and the results of the OLS regression follow.

Table 10

Pairwise Correlation Matrix for AP, ST, CM, DO, PR, and MACT: Pennsylvania
(1950 Through 1975)

	AP	ST	CM	DO	PR	MACT
AP	1.0000	-0.71968	0.62619	0.64265	0.10079	0.82182
ST	-0.71968	1.0005	-0.70231	-0.52790	-0.0023741	-0.54476
CM	0.62619	-0.70231	1.0000	0.48617	-0.29024	0.47543
DO	0.64265	-0.52790	0.48617	1.0000	-0.14283	0.38370
PR	0.10079	-0.0023741	-0.29024	-0.14283	1.0000	0.46597
MACT	0.82182	-0.54476	0.47543	0.38370	0.46597	1.0000



```
                         PLOT OF ACTUAL(*) AND FITTED(+) VALUES                PLOT OF RESIDUALS(*)
 ID      ACTUAL        FITTED
                                                                  RESIDUAL
1950      4.930         4.979                                                        0.0
1951      5.160         5.618                                   -0.488E-01
1952      5.420         5.136                                   -0.458
1953      5.890         5.593                                    0.284
1954      6.750         5.697                                    0.297
1955      7.020         7.273                                     1.05
1956      7.390         7.868                                   -0.253
1957      7.970         8.325                                   -0.478
1958      8.820         9.135                                   -0.355
1959      9.720         9.658                                   -0.315
1960      10.31         10.80                                    0.619E-01
1961      10.87         11.79                                   -0.494
1962      12.33         12.16                                   -0.920
1963      12.91         12.82                                    0.171
1964      13.62         13.55                                    0.865E-01
1965      14.37         14.03                                    0.738E-01
1966      14.66         14.28                                    0.345
1967      15.42         14.34                                    0.377
1968      15.59         13.89                                     1.08
1969      14.51         14.22                                     1.70
1970      13.37         14.32                                    0.285
1971      11.75         13.04                                   -0.946
1972      10.99         11.76                                    -1.29
1973      10.35         10.42                                   -0.772
1974      9.640         8.036                                   -0.719E-01
1975      8.360         9.370                                     1.60
                                                                 -1.01
```

Figure 29. Plots for Productivity Model, 1950 Through 1975: Pennsylvania (OLS).

Variable	Factor Loadings
AP	0.87764
ST	-0.87331
CM	0.84507
DO	0.77775
PR	-0.14199

$$(18)\ PRY_t = 11.4373 + 3.67565\ PC_t - 0.1635599\ MACT_t$$
$$(0.434173)(0.493643)****(0.0323267)\#\#\#\#\#$$

$R^2 = 0.7074$

F-statistic (2,23) = 27.8044

Durbin-Watson statistic = 0.7694

Standard error of the regression = 1.90169

Sum of squared residuals = 83.1776.

The coefficients of both the principal component and the Mine-Act variable are significant at the 99.0 and 99.5 percent confidence level, respectively. The Mine-Act variable has the expected negative sign. The F-statistic indicates that the equation is significant at the 99.0 percent confidence level. The percent of variance explained is approximately 70.7, lower than equation (17) not using a principal component. The Durbin-Watson statistic indicates positive autocorrelation (99.0 percent confidence level) . The pairwise correlation matrix below indicates the degree of multicollinearity is low.

	PC	MACT
PC	1.0000	0.63748
MACT	0.63748	1.0000

A plot of actual and fitted values and a plot of the residuals are presented in Figure 30. The residuals plot gives no indication of the presence of heteroskedasticity.

Examination of the data for weighted-average seam thickness reveals that the maximum is 5.6 feet and the minimum is 5.1 feet, a variation of only 0.5 foot (Table 9). It is thought that in the particular case under study, seam thickness is not a variable affecting the level of productivity achieved in Pennsylvania. In other words, I again consider seam thickness to be essentially a constant over the period of investigation. Hence, to test the importance of the seam thickness variable in explaining productivity, the model was run without this variable. The results for the OLS regression of the model with seam thickness eliminated are:

$$
\begin{aligned}
(19)\quad PRY_t = {} & \underset{(2.94682)}{3.00172} - \underset{(4.16337)}{0.0894420}\, AP_t + \underset{(0.00826004)\#\#\#\#\#}{0.101861}\, CM_t \\
& + \underset{(0.0121557)\#}{0.0206485}\, DO_t - \underset{(0.0333457)\#}{0.0540173}\, PR_t - \underset{(0.0289616)\#\#\#\#\#}{0.107657}\, MACT_t
\end{aligned}
$$

$R^2 = 0.9489$

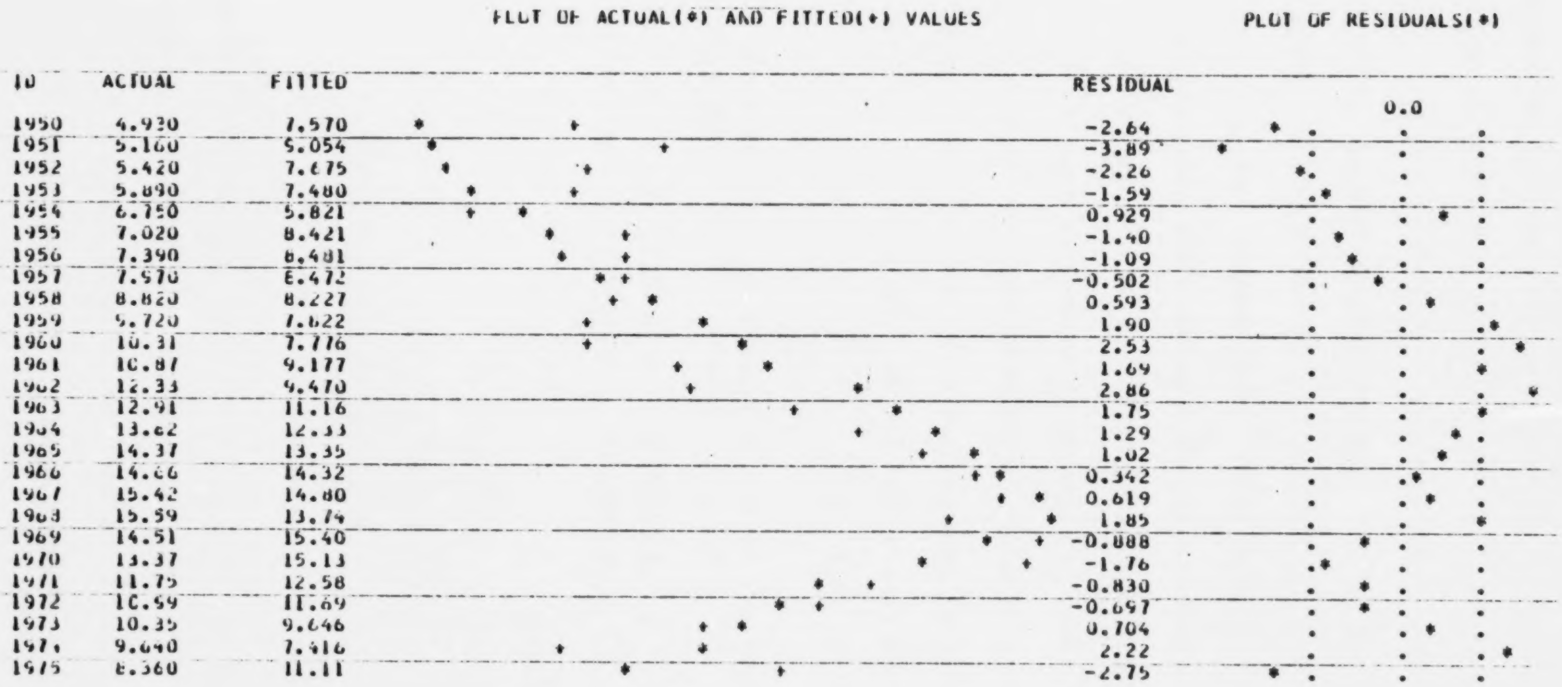
F-statistic (5,20) = 74.2867

Durbin-Watson statistic = 1.3747

Standard error of the regression = 0.852208

Sum of squared residuals = 14.5252 .

Coefficients of the Mine-Act variable and percent mined by continuous miners are both significant at the 99.5 percent confidence level. Days in operation and price have coefficients that are significant at the 90.0 percent confidence level. All of the significant coefficients have



ID	ACTUAL	FITTED	RESIDUAL
1950	4.930	7.570	-2.64
1951	5.160	9.054	-3.89
1952	5.420	7.675	-2.26
1953	5.890	7.480	-1.59
1954	6.750	5.821	0.929
1955	7.020	8.421	-1.40
1956	7.390	8.481	-1.09
1957	7.970	8.472	-0.502
1958	8.820	8.227	0.593
1959	9.720	7.822	1.90
1960	10.31	7.776	2.53
1961	10.87	9.177	1.69
1962	12.33	9.470	2.86
1963	12.91	11.16	1.75
1964	13.62	12.33	1.29
1965	14.37	13.35	1.02
1966	14.66	14.32	0.342
1967	15.42	14.80	0.619
1968	15.59	13.74	1.85
1969	14.51	15.40	-0.888
1970	13.37	15.13	-1.76
1971	11.75	12.58	-0.830
1972	10.99	11.69	-0.697
1973	10.35	9.646	0.704
1974	9.640	7.416	2.22
1975	8.360	11.11	-2.75

Figure 30. Plots for Productivity Model Using Principal Components, 1950 Through 1975: Pennsylvania (OLS).

the expected signs. The only coefficient that is not significant is that of AP. The equation is significant at the 99.0 percent confidence level, and almost 95.0 percent of the variance is explained. The Durbin-Watson statistic is in the inconclusive region. However, positive autocorrelation is indicated by the Hart-von Neumann test (95.0 percent confidence level). A plot of actual and fitted values and a plot of the residuals are presented in Figure 31. No sign of heteroskedasticity is evident in the residuals plot.

Again, the method of principal components was used to correct for multicollinearity. The factor loadings for the principal component and the results of the ordinary least squares regression follow.

Variable	Factor Loadings
AP	0.86464
CM	0.84267
DO	0.83102
PR	-0.22988

$$\begin{array}{llll} (20)\ PRY_t = & 11.3446 & +\ 3.55629\ PC_t & -\ 0.150128\ MACT_t \\ & (0.426336) & (0.471680)^{****} & (0.0308885)^{\#\#\#\#\#} \end{array}$$

$R^2 = 0.7126$

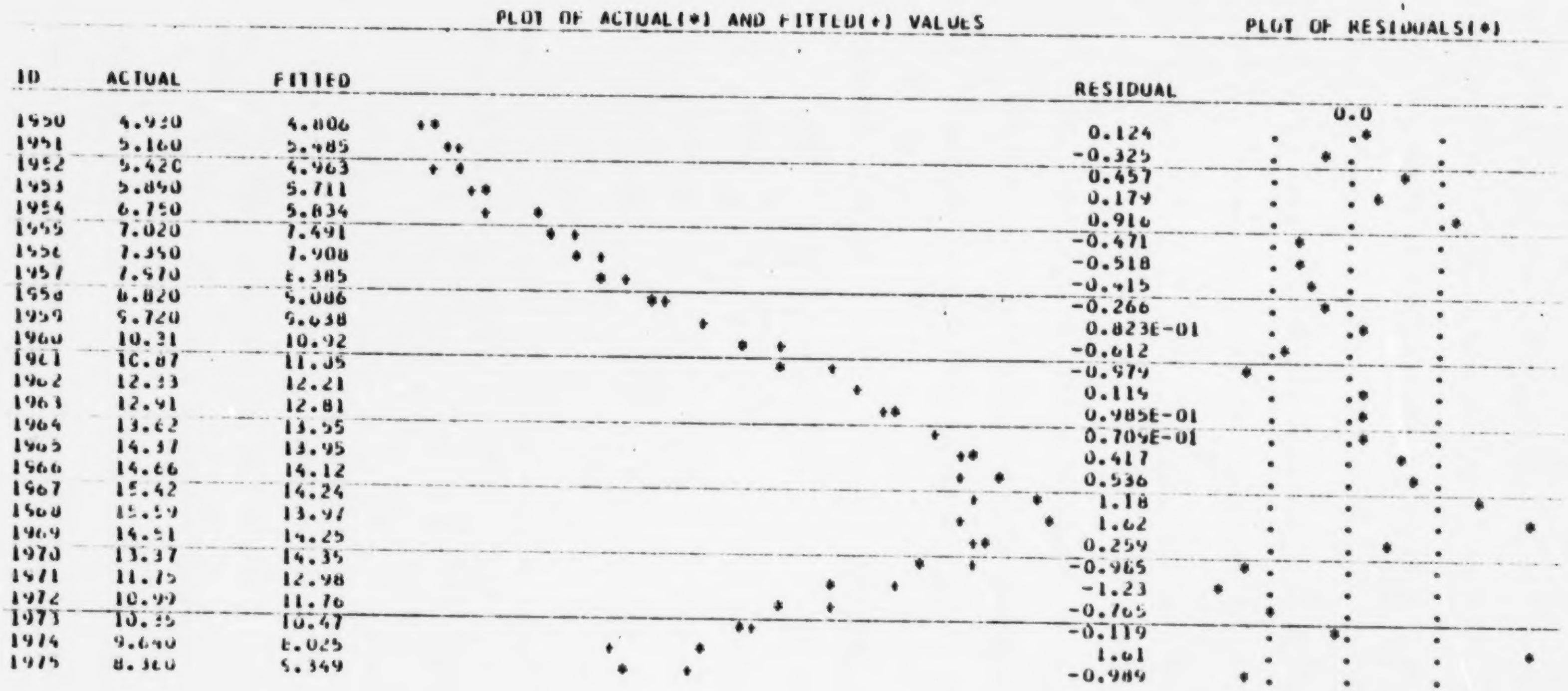
F-statistic (2,23) = 28.5075

Durbin-Watson statistic = 1.0084

Standard error of the regression = 1.88490

Sum of squared residuals = 81.7157.

The principal component and the Mine-Act variable have coefficients that are significant at the 99.0 and 99.5 percent confidence level,



```
ID      ACTUAL      FITTED      RESIDUAL
1950    4.930       4.806        0.124
1951    5.160       5.485       -0.325
1952    5.420       4.963        0.457
1953    5.890       5.711        0.179
1954    6.750       5.834        0.916
1955    7.020       7.491       -0.471
1956    7.390       7.908       -0.518
1957    7.970       8.385       -0.415
1958    8.820       9.086       -0.266
1959    9.720       9.638        0.823E-01
1960    10.31       10.92       -0.612
1961    10.87       11.85       -0.979
1962    12.33       12.21        0.119
1963    12.91       12.81        0.985E-01
1964    13.62       13.55        0.709E-01
1965    14.37       13.95        0.417
1966    14.66       14.12        0.536
1967    15.42       14.24        1.18
1968    15.59       13.97        1.62
1969    14.51       14.25        0.259
1970    13.37       14.35       -0.985
1971    11.75       12.98       -1.23
1972    10.99       11.76       -0.765
1973    10.35       10.47       -0.119
1974    9.640       8.025        1.61
1975    8.360       9.349       -0.989
```

Figure 31. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1975: Pennsylvania (OLS).

respectively. The Mine-Act variable has the expected negative sign. The F-statistic indicates that the equation is significant at the 99.0 percent confidence level; just over 71.0 percent of the variance is explained. The Durbin-Watson statistic indicates positive autocorrelation (95.0 percent confidence level). The degree of multicollinearity is moderate, as indicated by the correlation matrix below.

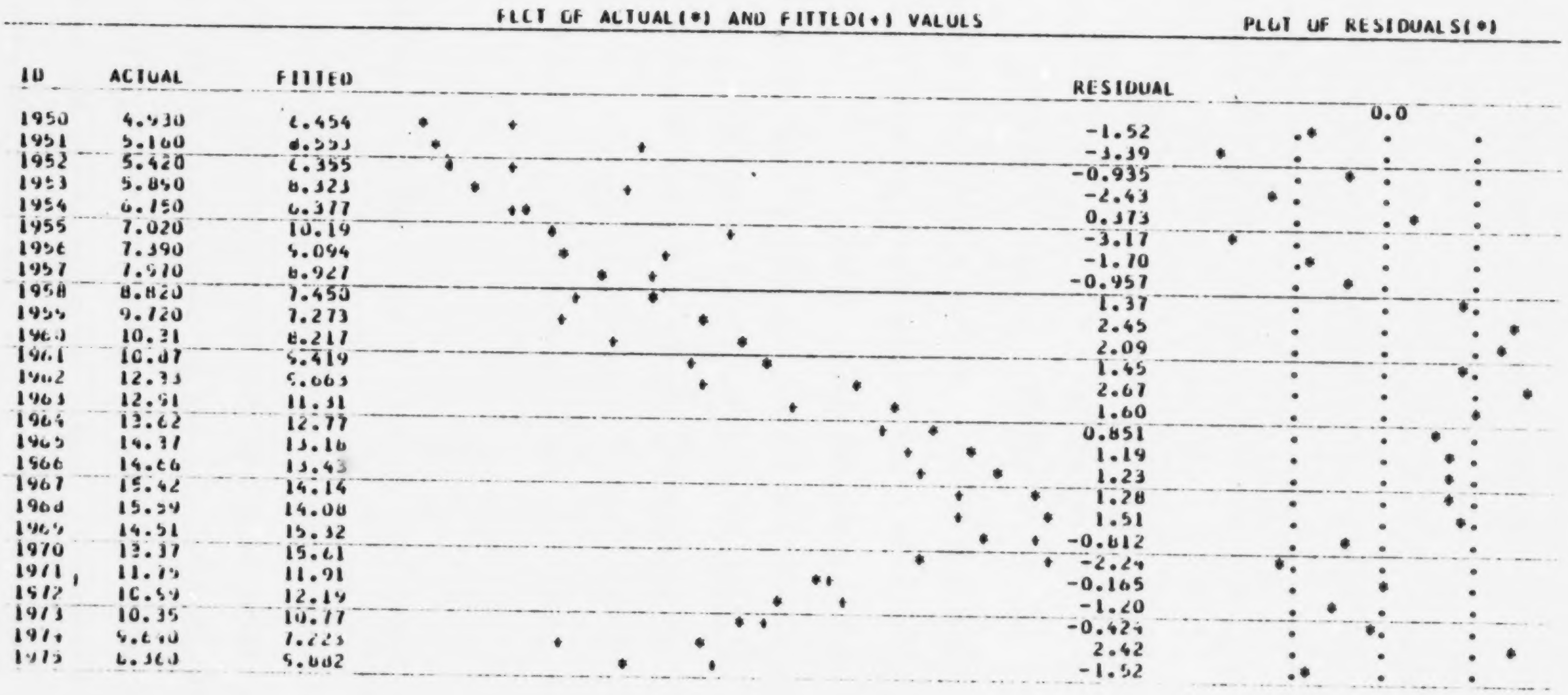
	PC	MACT
PC	1.0000	0.60103
MACT	0.60103	1.0000

A plot of actual and fitted values and a plot of the residuals are presented in Figure 32. The residuals plot gives no indication of the presence of heteroskedasticity.

A comparison of the results for Equations 17 and 19 indicates that the seam-thickness variable is not significant. The F-statistic for testing the hypothesis that the coefficient of seam thickness equals zero is 0.32 (1,19). This is less than the critical F (1,19; 0.01), 8.18; therefore, the hypothesis cannot be rejected at the 99.0 percent confidence level.

Results of Regressions for 1950 Through 1969 and Predictions of Productivity

This section presents derivations of predictions of productivity levels that might have been obtained in 1970 through 1975 if the Coal Mine Health and Safety Act had not been passed. First, a time trend of productivity from 1950 through 1969 is used to predict possible levels of productivity; second, estimates of the multivariate model were made using actual values of the independent variables for 1950



ID	ACTUAL	FITTED	RESIDUAL
1950	4.930	6.454	-1.52
1951	5.160	8.553	-3.39
1952	5.420	6.355	-0.935
1953	5.890	8.323	-2.43
1954	6.750	6.377	0.373
1955	7.020	10.19	-3.17
1956	7.390	9.094	-1.70
1957	7.970	8.927	-0.957
1958	8.820	7.450	1.37
1959	9.720	7.273	2.45
1960	10.31	8.217	2.09
1961	10.87	9.419	1.45
1962	12.33	9.663	2.67
1963	12.91	11.31	1.60
1964	13.62	12.77	0.851
1965	14.37	13.18	1.19
1966	14.66	13.43	1.23
1967	15.42	14.14	1.28
1968	15.59	14.08	1.51
1969	14.51	15.32	-0.812
1970	13.37	15.61	-2.24
1971	11.75	11.91	-0.165
1972	10.99	12.19	-1.20
1973	10.35	10.77	-0.424
1974	9.640	7.223	2.42
1975	8.360	9.882	-1.52

Figure 32. Plots for Productivity Model Excluding Seam Thickness Using Principal Components, 1950 Through 1975: Pennsylvania (OLS).

through 1969. Predictions of productivity in the absence of new federal legislation are made using values of the independent variables in 1970 through 1975, and these are compared to actual levels of productivity. Third, predictions are made based on the results of the model for 1950 through 1975 by subtracting the negative influence of MACT on productivity.

It is possible that the legislation could have indirect effects on productivity by affecting the other independent variables in some way. To examine this possibility, the trend of each variable is re-examined. From Figure 23, it can be seen that the percent of coal mined by continuous mines shows a strongly increasing trend with no change of overall trend in 1969. Similarly, no change of trend in 1969 is evidenced in weighted-average seam thickness (Figure 24), weighted-average days in operation (Figure 25), or average production (Figure 26), suggesting that the Mine Act is unlikely to have seriously affected these variables. The effect of the Mine Act on costs has been accounted for by subtracting out the estimated portion of the actual costs that was due to the existence of the Mine Act. This has been more fully explained in the section on methods of investigation. Therefore, it is unlikely that there are any large indirect effects of the Mine Act on productivity.

Productivity shows a positive trend from 1950 through 1968 and declines thereafter. A simple regression of productivity with time (T) from 1 (1950) through 20 (1969) was run. The results are:

(21) $PRY_t = 3.601 + 0.6269\ T$

(0.276) (0.0233)#####

$R^2 = 0.9758$

F-statistic (1,18) = 725.90

Durbin-Watson statistic = 0.7201

Standard error of the regression = 0.60

Sum of squared residuals = 6.483.

This regression produces a residuals plot that shows a "u"-shaped pattern characteristic of positive autocorrelation (Figure 33). The Durbin-Watson statistic, 0.7201, shows high, positive autocorrelation (99.0 percent confidence level). The Cochrane-Orcutt technique does not remedy the positive autocorrelation (Durbin-Watson statistic = 1.07). As in the case of West Virginia, the best results are obtained by regressing against year (T), year-squared (T^2) and year-cubed (T^3), since the trend is actually curved over time (Figure 34). This regression produces the following results:

(22) $PRY_t = 5.352 - 0.262\ T + 0.1030\ T^2 - 0.003261\ T^3$

(0.365) (0.147)* (0.0161)****(0.000503)****

$R^2 = 0.9933$

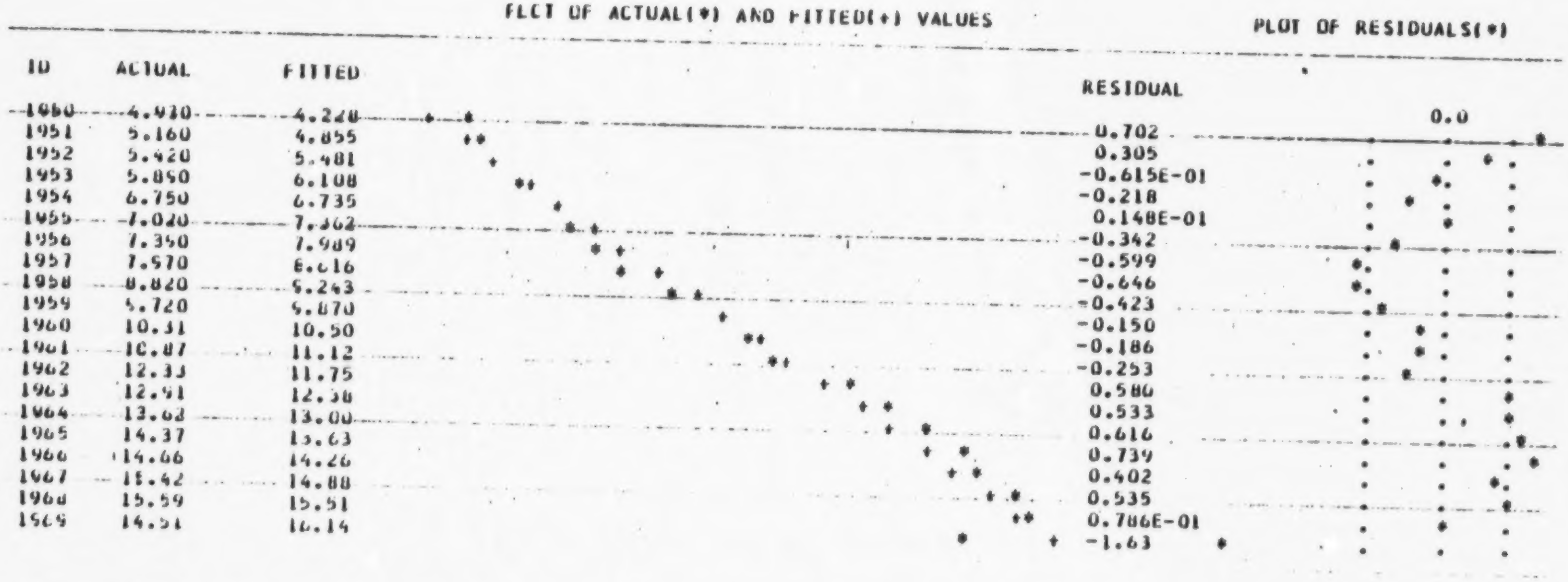
F-statistic (3,16) = 793.064

Durbin-Watson statistic = 1.4018

Standard error of the regression = 0.334380

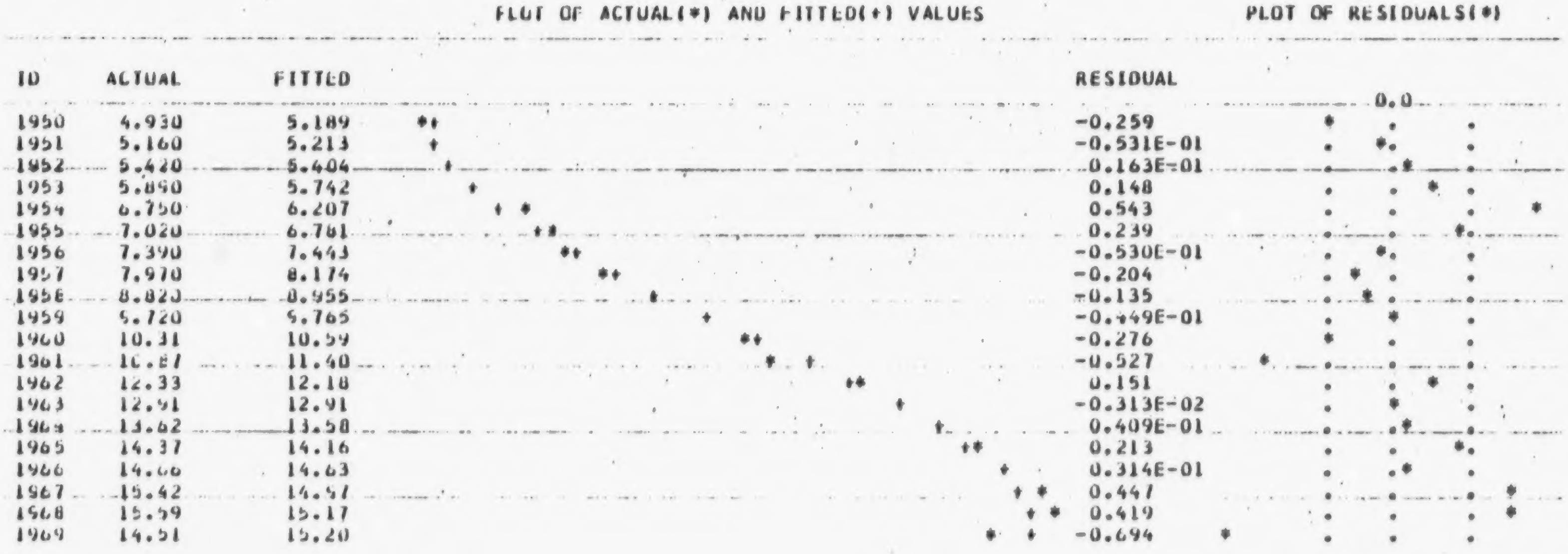
Sum of squared residuals = 1.78896.

The points in the residuals plot of this regression appear to be more random than the linear trend (Figure 34). The Durbin-Watson statistic falls in the inconclusive region. However, the Hart-von Neumann



```
                      PLOT OF ACTUAL(*) AND FITTED(+) VALUES                 PLOT OF RESIDUALS(*)
ID      ACTUAL      FITTED
                                                                  RESIDUAL
                                                                                         0.0
1950    4.930       4.228                                         0.702
1951    5.160       4.855                                         0.305
1952    5.420       5.481                                        -0.615E-01
1953    5.890       6.108                                        -0.218
1954    6.750       6.735                                         0.148E-01
1955    7.020       7.362                                        -0.342
1956    7.390       7.989                                        -0.599
1957    7.970       8.616                                        -0.646
1958    8.820       9.243                                        -0.423
1959    9.720       9.870                                        -0.150
1960    10.31       10.50                                        -0.186
1961    10.87       11.12                                        -0.253
1962    12.33       11.75                                         0.580
1963    12.91       12.38                                         0.533
1964    13.62       13.00                                         0.616
1965    14.37       13.63                                         0.739
1966    14.66       14.26                                         0.402
1967    15.42       14.88                                         0.535
1968    15.59       15.51                                         0.786E-01
1969    14.51       16.14                                        -1.63
```

Figure 33. Plots for Time Trend of Productivity, 1950 Through 1969: Pennsylvania (OLS).



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                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES            PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                RESIDUAL
                                                                           0.0
1950    4.930       5.189                                 -0.259
1951    5.160       5.213                                 -0.531E-01
1952    5.420       5.404                                  0.163E-01
1953    5.890       5.742                                  0.148
1954    6.750       6.207                                  0.543
1955    7.020       6.781                                  0.239
1956    7.390       7.443                                 -0.530E-01
1957    7.970       8.174                                 -0.204
1958    8.820       8.955                                 -0.135
1959    9.720       9.765                                 -0.449E-01
1960    10.31       10.59                                 -0.276
1961    10.87       11.40                                 -0.527
1962    12.33       12.18                                  0.151
1963    12.91       12.91                                 -0.313E-02
1964    13.62       13.58                                  0.409E-01
1965    14.37       14.16                                  0.213
1966    14.66       14.63                                  0.314E-01
1967    15.42       14.97                                  0.447
1968    15.59       15.17                                  0.419
1969    14.51       15.20                                 -0.694
```

Figure 34. Plots for Regression of Productivity on Year, Year^2, and Year^3, 1950 Through 1969: Pennsylvania (OLS).

test indicates no autocorrelation. Over 99.0 percent of the variance is explained. Figure 34 also shows plots of actual and predicted values.

Values of productivity were extrapolated for the years 1970 through 1975 using both Equations 21 and 22 (Table 11). The predictions of productivity based on the simple straight-line time trend show increasing productivity from 1970 through 1975, as would be expected. In 1975, the prediction is approximately 19.9 tons per man-day, as compared to an actual rate of around 8.4 tons per man-day. The predicted rate represents an increasingly larger percentage increase over the actual rate from 1970 (25.0 percent) to 1975 (138.0 percent). The corresponding values for 1971 through 1974 are 48.0, 64.0, 80.0, and 100.0 percent, respectively. The more complex time trend of Equation 22 predicts productivities that are greater than actual rates but less than those predicted by Equation 21 (Table 11). In this case, the predicted percentage increases over actual rates for 1970 through 1975 are more stable from year to year; these are 13.0, 25.0, 28.0, 26.0, and 29.0 percent, respectively. In contrast with the simple linear time trend, this equation takes the curvature of the trend into account and predicts declining productivities over the six-year period.

Similarly, a regression was run for 1950 through 1969 with productivity as a function of average production, weighted-average seam thickness, percent mined by continuous miners, weighted-average days in operation, and price. The results are:

Table 11

Comparison of Predicted Levels of Productivity Based on Time Trends and on Multiple Regressions With Actual Levels of Productivity in Pennsylvania

Year	Productivity (tons per man-day)				
	Actual	Based on Simple Time Trend	Based on T, T^2, T^3 Time Trend	Based on AP, ST, CM, DO, and PR (CORC)	Based on AP, CM, DO, and PR (OLS)
1970	13.37	16.77 (±1.39)	15.05 (±1.05)	16.78 (±1.37)	16.97 (±1.35)
1971	11.75	17.39 (±1.41)	14.69 (±1.31)	16.04 (±1.35)	16.02 (±1.36)
1972	10.99	18.02 (±1.43)	14.11 (±1.65)	15.86 (±1.59)	16.36 (±1.58)
1973	10.35	18.65 (±1.45)	13.28 (±2.10)	15.43 (±2.07)	16.19 (±2.04)
1974	9.64	19.27 (±1.47)	12.19 (±2.65)	10.58 (±4.89)	11.90 (±4.69)
1975	8.36	19.90 (±1.49)	10.81 (±3.30)	8.04 (±6.89)	9.83 (±6.54)

Note: Prediction intervals for a 95.0 percent confidence level are given in parentheses.

$$(23)\ PRY_t = \underset{(7.87188)}{18.9727} + \underset{(2.95836)\#\#\#\#}{7.78187}\ AP_t - \underset{(0.105031)}{0.0856331}\ ST_t$$

$$+ \underset{(0.0113160)\#\#\#\#\#}{0.0822779}\ CM_t + \underset{(0.00842289)}{0.00131684}\ DO_t - \underset{(0.0829353)\#\#\#}{0.198472}\ PR_t$$

$R^2 = 0.9889$

F-statistic (5,14) = 249.426

Durbin-Watson statistic = 1.3972

Standard error of the regression = 0.460820

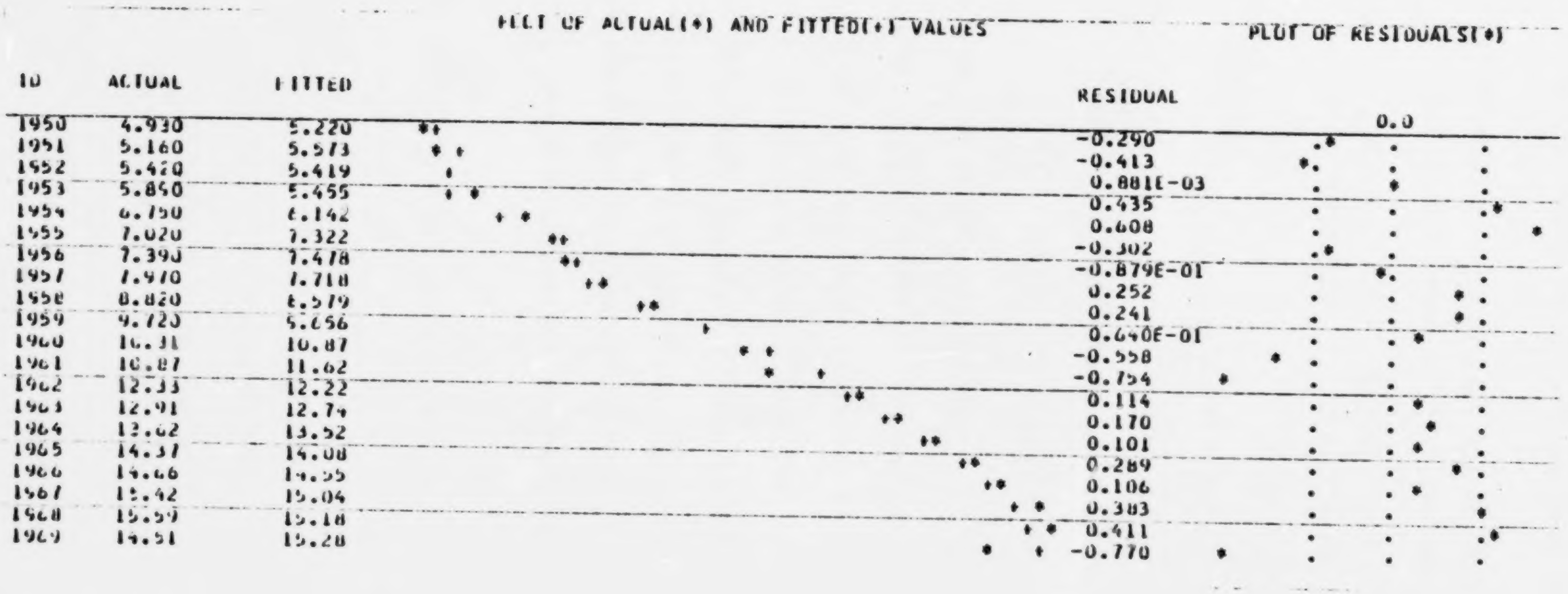
Sum of squared residuals = 2.97297.

Three of the coefficients are significant at percentage confidence levels greater than 90.0: AP(99.0), CM(99.5), and PR(97.5). All coefficients except that of weighted-average seam thickness have the expected signs. Since the coefficient of ST is not significant, this unexpected sign presents no serious problem. The coefficient of DO is not significant. The equation is significant at the 99.0 percent confidence level, and almost 99.0 percent of the variance is explained. The Durbin-Watson statistic is in the inconclusive region. However, the Hart-von Neumann test indicates positive autocorrelation (95.0 percent confidence level). The pairwise correlation matrix is shown in Table 12. Price and percent mined by continuous miners, both of which are significant, are highly correlated (-0.93). A plot of actual and fitted values and a plot of residuals are presented in Figure 35. The residuals plot gives no indication of the presence of heteroskedasticity.

Table 12

Pairwise Correlation Matrix for
AP, ST, CM, DO, and PR: Pennsylvania
(1950 Through 1969)

	AP	ST	CM	DO	PR
AP	1.0000	-0.53519	0.38413	0.65201	-0.56256
ST	-0.53519	1.0008	-0.57914	-0.43352	0.66257
CM	0.38413	-0.57914	1.0000	0.36170	-0.92763
DO	0.65201	-0.43352	0.36170	1.0000	-0.56629
PR	-0.56256	0.66257	-0.92763	-0.56629	1.0000



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ID      ACTUAL      FITTED                RESIDUAL
1950    4.930       5.220                 -0.290
1951    5.160       5.573                 -0.413
1952    5.420       5.419                  0.881E-03
1953    5.850       5.455                  0.435
1954    6.750       6.142                  0.608
1955    7.020       7.322                 -0.302
1956    7.390       7.478                 -0.879E-01
1957    7.970       7.718                  0.252
1958    8.820       8.579                  0.241
1959    9.720       9.656                  0.640E-01
1960    10.31       10.87                 -0.558
1961    10.87       11.62                 -0.754
1962    12.33       12.22                  0.114
1963    12.91       12.74                  0.170
1964    13.62       13.52                  0.101
1965    14.37       14.08                  0.289
1966    14.66       14.55                  0.106
1967    15.42       15.04                  0.383
1968    15.59       15.18                  0.411
1969    14.51       15.28                 -0.770
```

Figure 35. Plots for Productivity Model, 1950 Through 1969: Pennsylvania (OLS).

Applying the Cochrane-Orcutt technique yields:

$$\begin{array}{llllll}
(24)\ PRY_t = & 24.3971 & + 6.93710\ AP_t & - 0.0928779\ ST_t & + 0.0715133\ CM_t \\
 & (10.0401) & (3.70136)\#\# & (0.123960) & (0.0156062)\#\#\#\#\# \\
 & - 0.00763881\ DO_t & - 0.255640\ PR_t & & \\
 & (0.00755052) & (0.0883991)\#\#\#\# & &
\end{array}$$

$R^2 = 0.9897$

F-statistic (5,13) = 250.226

Durbin-Watson statistic = 1.4640

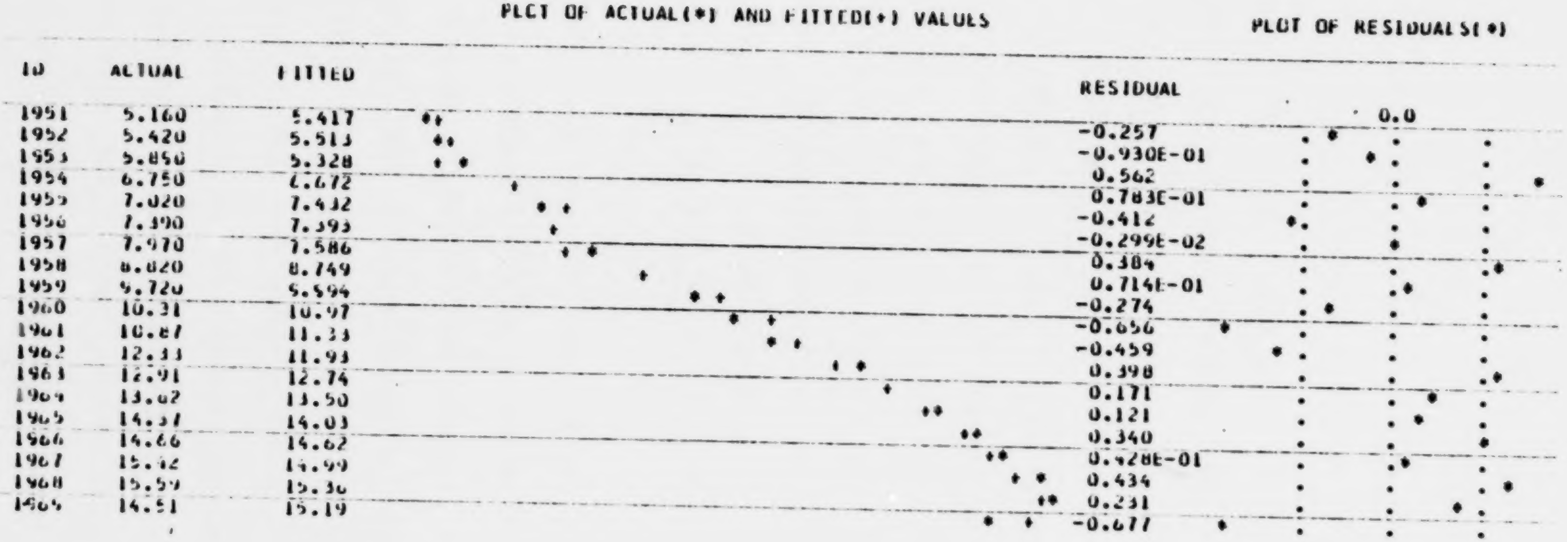
Standard error of the regression = 0.434596

Sum of squared residuals = 2.45536.

For this equation, also, the coefficients of CM, PR, and AP are significant at confidence levels of 99.5 percent, 99.0 percent, and 95.0 percent, respectively. All of the significant variables have coefficients with the expected signs. The coefficients of ST and DO are not significant. The equation is significant (99.0 percent confidence level) and explains almost 99.0 percent of the variation in productivity. The Durbin-Watson test is inconclusive, but the Hart-von Neumann test indicates there is no autocorrelation. Plots of residuals and actual and fitted values are shown in Figure 36 .

Again, eliminating the seam-thickness variable, the results of the OLS regression are:

$$\begin{array}{llll}
(25)\ PRY_t = & 14.0421 & + 8.34718\ AP_t & + 0.0820005\ CM_t \\
 & (4.98273) & (2.84363)\#\#\#\# & (0.0111838)\#\#\#\#\# \\
 & + 0.000980699\ DO_t & - 0.213340\ PR_t & \\
 & (0.00831825) & (0.0799962)\#\#\#\# &
\end{array}$$



ID	ACTUAL	FITTED	RESIDUAL
1951	5.160	5.417	-0.257
1952	5.420	5.513	-0.930E-01
1953	5.890	5.328	0.562
1954	6.750	6.672	0.783E-01
1955	7.020	7.432	-0.412
1956	7.390	7.393	-0.299E-02
1957	7.970	7.586	0.384
1958	8.820	8.749	0.714E-01
1959	9.720	9.994	-0.274
1960	10.31	10.97	-0.656
1961	10.87	11.33	-0.459
1962	12.33	11.93	0.398
1963	12.91	12.74	0.171
1964	13.62	13.50	0.121
1965	14.37	14.03	0.340
1966	14.66	14.62	0.428E-01
1967	15.42	14.99	0.434
1968	15.59	15.36	0.231
1969	14.51	15.19	-0.677

Figure 36. Plots for Productivity Model, 1950 Through 1969: Pennsylvania (CORC).

R^2 = 0.9884

F-statistic (4,15) = 318.739

Durbin-Watson statistic = 1.3615

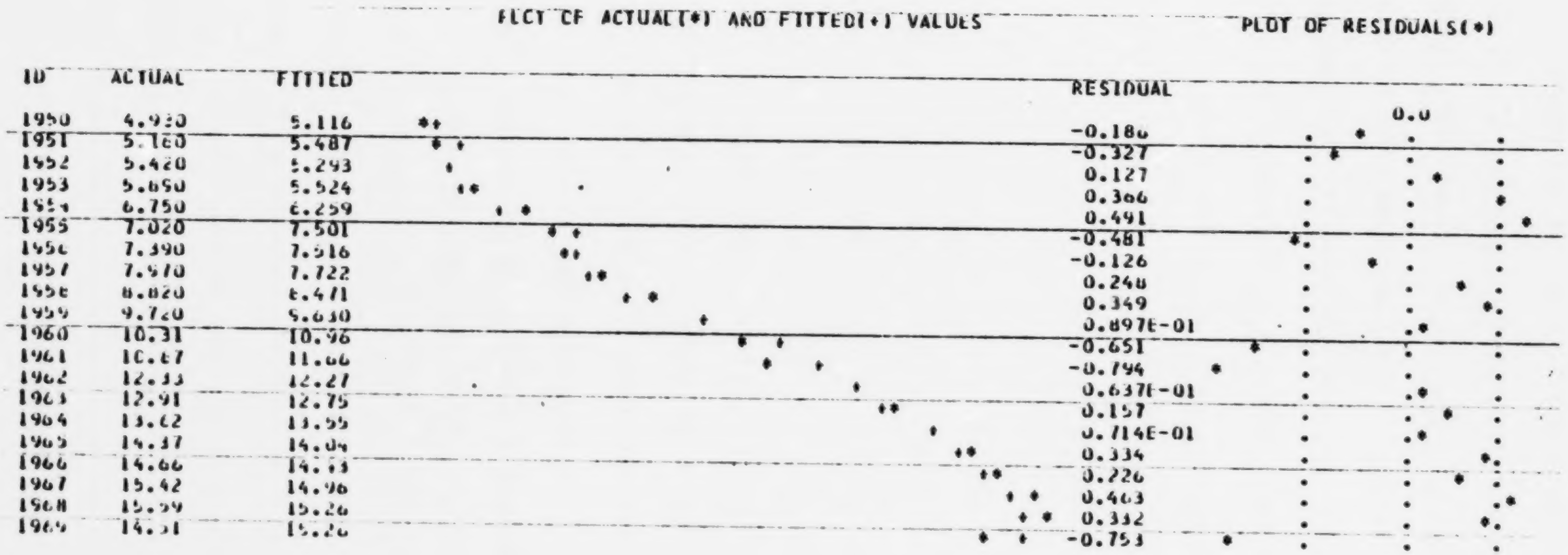
Standard error of the regression = 0.455641

Sum of squared residuals = 3.11414 .

Three coefficients are highly significant: AP(99.0 percent), CM(99.5 percent), and PR (99.0 percent), and all coefficients have the expected signs. The equation is significant at the 99.0 percent confidence level, and almost 99.0 percent of the variance is explained. The Durbin-Watson test is inconclusive for autocorrelation; however, the Hart-von Neumann test indicates positive autocorrelation (95.0 percent confidence level)[4]. Plots of residuals and actual and fitted values are shown in Figure 37. There is no indication that heteroskedasticity is present. The F-statistic for testing the hypothesis that the coefficient of ST is equal to zero, using results of Equations 23 and 25 is 0.67. Since the critical F-statistic (1,14;0.05) is 4.6, the hypothesis is rejected.

Equations 24 and 25 were used to predict possible levels of productivity in 1970 through 1975 in the absence of the new legislation. These results are shown in Table 11 with 95.0 percent prediction intervals in parentheses. The estimates are very similar and, within the prediction intervals, they are essentially the same. The predictions based on the time trend involving year, year-squared, and year-cubed are within the prediction intervals of the estimates from the models. With one exception in 1975, all predicted levels are greater than actual levels, with the greatest differences being in the years 1970 through 1973.

Using the results of the model for 1950 through 1975, predictions of productivity without the Mine Act were made by adding the amount of



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                    PLCT CF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID     ACTUAL     FITTED                              RESIDUAL
                                                                          0.0
1950    4.930      5.116                              -0.186
1951    5.160      5.487                              -0.327
1952    5.420      5.293                               0.127
1953    5.890      5.524                               0.366
1954    6.750      6.259                               0.491
1955    7.020      7.501                              -0.481
1956    7.390      7.516                              -0.126
1957    7.970      7.722                               0.248
1958    8.820      8.471                               0.349
1959    9.720      9.630                               0.897E-01
1960    10.31      10.96                              -0.651
1961    10.87      11.66                              -0.794
1962    12.33      12.27                               0.637E-01
1963    12.91      12.75                               0.157
1964    13.62      13.55                               0.714E-01
1965    14.37      14.04                               0.334
1966    14.66      14.43                               0.226
1967    15.42      14.96                               0.463
1968    15.59      15.26                               0.332
1969    14.51      15.26                              -0.753
```

Figure 37. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1969: Pennsylvania (OLS).

productivity lost due to the Mine Act to the prediction of productivity. These predictions, shown in Table 13, are for levels of productivity that are greater than actual values in all years, with the prediction in 1975 for 13.6 tons per man-day. For comparison, the effects of the price of coal on productivity are shown in Table 13. The results show that the Mine Act had a greater influence on reducing productivity than changes in price. Percentage losses in productivity due to MACT are shown in Table 14. The results indicate that productivity was down due to the Mine Act by around 31.1 percent in 1975.

Summary

Some of the results of the regression are summarized in Tables 15 and 16. The relationships of the independent variables to productivity in the model using data for 1950 through 1975 may be summarized as follows: (1) average production is negatively related but not significant; (2) weighted-average seam thickness is negatively related by not significant; (3) percent mined by continuous miners is positively related and significant; (4) weighted-average days in operation is positively related and significant; (5) price is negatively related and significant; and (6) the Mine-Act variable is negatively related and highly significant. The regression analyses indicate that the effects of each independent variable on productivity in terms of approximate magnitude are:

(1) an increase of average production of 0.1 million tons decreases productivity by 0.1 ton per man-day;

(2) an increase in weighted-average seam thickness of 1.0 inch decreases productivity by 0.1 tons per man-day;

(3) an increase in percent mined by continuous miners of 1.0 increases productivity by 0.1 ton per man-day;

Table 13

Effect of MACT and PR on Productivity: Pennsylvania*

					Tons Per Man-Day							
Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Productivity Caused by MACT -((1) x (2))			(4) Prediction of Productivity from Model (95.0 percent confidence level)	(5) Prediction of Productivity Without MACT (4) + (3)			(6) Actual Productivity
		Mean			Low	Mean	High		Low	Mean	High	
1969	-0.168	-0.108	-0.047	0				14.25				14.51
1970				5.15924	0.24	0.56	0.87	14.35	14.59	14.91	15.22	13.37
1971				10.4678	0.49	1.13	1.76	12.98	13.47	14.11	14.74	11.75
1972				29.2330	1.37	3.16	4.91	11.76	13.13	14.92	16.67	10.99
1973				42.6833	2.01	4.61	7.17	10.47	12.48	15.08	17.64	10.35
1974				52.0947	2.45	5.63	8.75	8.03	10.48	13.61	16.78	9.64
1975				39.1479	1.84	4.23	6.58	9.35	11.19	13.58	15.93	8.36

				Cents Per Million Btu		Tons Per Man-Day		
	(7) 95.0 Percent Confidence Interval for Coefficient of PR			(8) Value of PR	(9) Change in PR From 1969	(10) Reduction in Productivity Caused by Change in PR -((7) x (9))		
		Mean				Low	Mean	High
1969	-0.124	-0.054	0.016	36.1				
1970				30.3	-5.8	0.09	-0.31	-0.72
1971				34.3	-1.8	0.03	-0.10	-0.22
1972				36.6	0.5	-0.06	0.03	0.01
1973				39.6	3.5	-0.43	0.19	0.06
1974				58.7	22.6	-2.80	1.22	0.36
1975				69.1	33.0	-4.09	1.78	0.53

*Using results of Equation 19.

Table 14

Percentage Losses in Productivity Due to the Mine Act in Pennsylvania

Year	Using Predictions of Regression 19 (data through 1975) (percentage loss)
1970	3.8
1971	8.0
1972	21.2
1973	30.6
1974	41.2
1975	31.1
Average Per Year	22.7

Table 15

Results of Regressions Summary for Pennsylvania

Equation	Constant	AP	ST	CH	DO	PR	MACT	PC	T(Year)	T^2	T^3	R^2	S	SSR	Autocorrelation (Durbin-Watson Statistic)	F-Statistic
1950 Through 1975																
17(OLS)	10.429	-0.981	-0.105	0.099 #####	0.020 #	-0.060 #	-0.103 #####					0.95	0.87	14.28	+(1.39)	$59.86_{(6,19)}$
18(OLS)	11.437						-0.164 #####	3.676 ****				0.71	1.90	83.18	+(0.77)	$27.80_{(2,23)}$
19(OLS)	3.002	-0.089		0.102 #####	0.021 #	-0.054 #	-0.108 #####					0.95	0.85	14.53	+(1.37)	$74.29_{(5,20)}$
20(OLS)	11.345						-0.150 #####	3.556 ****				0.71	1.88	81.72	+(1.01)	$28.51_{(2.23)}$
1950 Through 1969																
21(OLS)	3.601								0.627 #####			0.98	0.60	6.48	+(0.72)	$725.90_{(1,18)}$
22(OLS)	5.352								-0.262 *	0.103 ####	-0.003 ****	0.99	0.33	1.79	None (1.40)	$793.06_{(3,16)}$
23(OLS)	18.973	7.782 ####	-0.086	0.082 #####	0.001	-0.198 ###						0.99	0.46	2.97	+(1.40)	$249.43_{(5,14)}$
24(OLS)	24.397	6.937 ##	-0.093	0.072 #####	-0.008	-0.256 ####						0.99	0.43	2.46	None (1.46)	$250.23_{(5,13)}$
25(OLS)	14,042	8.347 ####		0.082 #####	0.001	-0.213 ####						0.99	0.46	3.11	+(1.36)	$318.74_{(4,15)}$

Significance Levels:
* Significant at 90.0 percent confidence level (two-tail test)
**** Significant at 99.0 percent confidence level (two-tail test)
# Significant at 90.0 percent confidence level (one-tail test)
Significant at 95.0 percent confidence level (one-tail test)
Significant at 98.0 percent confidence level (one-tail test)
Significant at 99.0 percent confidence level (one-tail test)
Significant at 99.5 percent confidence level (one-tail test)

Table 16

Ninety-five Percent Confidence Intervals for Coefficients in Pennsylvania Regressions

Equation	AP	ST	CM	DO	PR	MACT	PC	T(Year)	T^2	T^3
					1950 Through 1975					
17(OLS)	-10.69 8.72	-0.49 0.28	0.08 0.12	-0.40 0.44	-0.13 0.01	-0.17 -0.04				
18(OLS)						-0.23 -0.10	2.65 4.70			
19(OLS)	- 8.77 8.60		0.08 0.12	-0.01 0.05	-0.12 0.02	-0.17 -0.05				
20(OLS)						-0.21 -0.09	2.58 4.53			
					1950 Through 1969					
21(OLS)								0.58 0.68		
22(OLS)								-0.57 0.05	0.07 0.14	-0.004 -0.002
23(OLS)	1.44 14.13	-0.31 0.14	0.06 0.11	-0.02 0.02	-0.38 -0.02					
24(CORC)	-1.06 14.93	-0.36 0.17	0.04 0.11	-0.02 0.01	-0.45 -0.06					
25(OLS)	2.29 14.40		0.06 0.11	-0.02 0.02	-0.38 -0.04					

(4) an increase in weighted-average days in operation of 10.0 increases productivity by 0.2 ton per man-day;

(5) an increase in the price of coal of 1.0 cent per million Btu decreases productivity by 0.05 ton per man-day; and

(6) an increase in the severity of Act enforcement represented by a risk in inspections per mine by 10.0 decreases productivity by 1.1 tons per man-day.

The results of these regressions for Pennsylvania indicate that the Mine Act was responsible for losses in productivity in 1970 through 1975 of approximately 4, 8, 21, 31, 41, and 31 percent, respectively.

Illinois

Data and Trends of Variables

The data used for Illinois are presented in Table 17. The state data on productivity (derived from figures on employment, days worked, and production) for the years 1953 through 1975, seam thickness, days in operation, and average production were obtained from the Illinois Annual Coal, Oil, and Gas Reports. Data are complete only for shipping mines (those mines selling coal outside the local area). Local mines are not included in the data set. Other data sources are as given in the section on Methods of Investigation. Productivity data could not be determined consistently with later years for 1950 through 1952. This is because employment data in the annual reports are incomplete for these years. The approach taken was to estimate productivity values for these years using the time trend from 1953 through 1969. The equation used for these estimations is:

$$(26)\quad PRY_t = \underset{(2.21)}{8.72} + \underset{(0.665)}{0.557T} + \underset{(0.0599)}{0.0423T^2} - \underset{(0.00165)}{0.00205T^3}$$

$R^2 = 0.969$

F-statistic (3,13) = 134.84.

The predictions are given in Table 17. The predictions and 95.0 percent prediction intervals for 1950, 1951, and 1952 are (9.31 ± 3.69), (9.98 ± 2.78), and (10.71 ± 2.11), respectively.

The trend of productivity in Illinois for the years 1950 through 1975 is shown in Figure 38. There was a steady increase in output per man-day from 1950 (9.31, estimated) through 1969 (20.92), then the trend became negative over time, reaching 14.21 in 1975. This is comparable to the average productivity achieved in 1956. In the years 1950

Table 17

Illinois Data

Year	Productivity PRY (tons-per man-day)	Average Production AP^a (tons)	Weighted-Average Seam Thickness ST (feet)	Percent Mined by Continuous Miners CM (percent)	Weighted-Average Days in Operation DO	Actual Price of Coal, 1975 Dollars PR_A (cents per million Btu)	Price of Coal Under the Assumption of No-Act, 1975 dollars PR (cents per million Btu)	Number of Inspections Per Mine Under CMHSA MACT
1950	9.31	344440	7.31	0.6	194	60.5	60.5	0.0
1951	9.98	333067	7.37	1.2	185	56.9	56.9	0.0
1952	10.71	332540	7.29	2.5	174	55.9	55.9	0.0
1953	11.38	416935	7.27	5.3	188	55.3	55.3	0.0
1954	12.10	410495	7.35	7.6	179	52.6	52.6	0.0
1955	13.61	516570	7.27	9.3	205	49.6	49.6	0.0
1956	14.31	597769	7.30	16.8	215	48.7	48.7	0.0
1957	15.42	606816	7.41	21.8	207	48.9	48.9	0.0
1958	14.64	609140	7.64	24.5	199	47.9	47.9	0.0
1959	15.64	589313	7.62	25.4	210	47.1	47.1	0.0
1960	16.74	598853	7.50	29.8	213	46.1	46.1	0.0
1961	18.54	704066	7.48	34.3	204	45.5	45.5	0.0
1962	19.52	843723	7.48	34.3	219	44.7	44.7	0.0
1963	19.55	927252	7.49	36.0	223	43.9	43.9	0.0
1964	19.74	858018	7.52	36.0	228	42.7	42.7	0.0
1965	19.67	1030730	7.55	39.1	232	40.9	40.9	0.0
1966	20.14	1215960	7.62	51.7	242	39.1	39.1	0.0
1967	20.49	1284720	7.60	52.7	249	38.1	38.1	0.0
1968	19.85	1022950	7.66	53.8	229	37.7	37.7	0.0
1969	20.92	1077590	7.44	59.3	248	38.1	38.1	0.0
1970	19.87	1090190	7.39	57.7	245	41.1	35.0	0.0
1971	17.29	1090890	7.37	69.0	222	45.0	38.0	5.15924
1972	16.34	1219840	7.37	77.0	247	48.3	38.5	10.4678
1973	17.24	1357390	7.28	82.4	244	51.2	41.0	29.2330
1974	16.03	1352350	7.31	78.8	229	59.5	45.1	42.6833
1975	14.21	1518100	7.28	84.5	245	75.5	57.2	39.1479

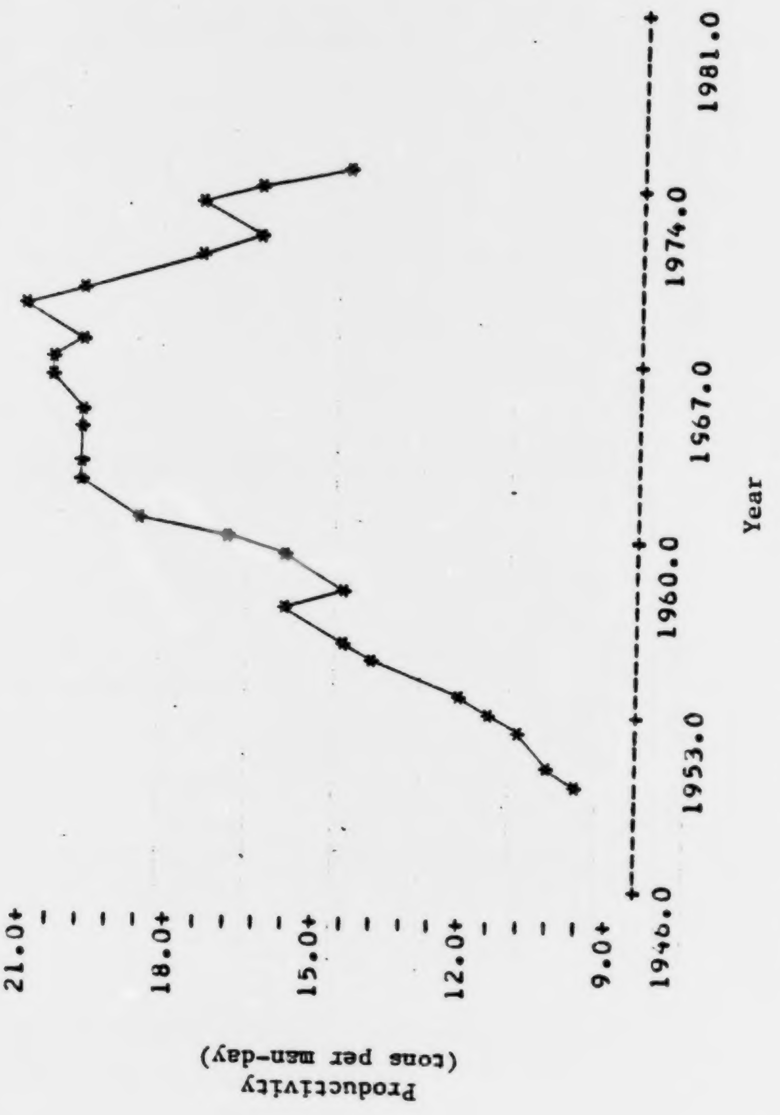


Figure 38. Trend of Productivity in Underground Coal Mines: Illinois (1950 Through 1975)

(estimated) through 1955, the total increase in productivity was 46.2 percent; in 1955 through 1960, the increase was 23.0 percent; between 1960 and 1965, productivity increased by 17.5 percent; and from 1965 to 1969, the increase was only 6.4 percent. Thus, the percentage increase declined throughout this period. The overall decrease in productivity from 1969 through 1975 was 32.1 percent.

Using piecewise regression, it was found that the change in the trend of productivity with time since the 1969 Coal Mine Health and Safety Act took effect is statistically significant at the 99.0 percent confidence level. The results for this regression using a join point of 20 (1969) are:

$$(27)\ PRY_t = \underset{(0.464)}{9.562} + \underset{(0.0370)^{****}}{0.6136\ X_1} - \underset{(0.164)^{****}}{1.939\ X_2\ (X_1 - 20)}$$

$R^2 = 0.923$

F-statistic (2,23) = 136.97

Standard error of the regression = 1.02

****Significant at the 99.0 percent confidence level.

Percent mined by continuous miners (Figure 39) and average production (Figure 40) show strong, positive trends over the entire 26-year period (99.0 percent confidence level). Although weighted-average seam thickness (Figure 41) varies only slightly over the time period (maximum - 7.66 feet, minimum - 7.27 feet), there is an overall increasing trend through 1958, a decreasing trend through 1962, then an increasing trend through 1968. There is a declining trend after 1968 (99.0 percent confidence level). Weighted-average days in operation (Figure 42) shows an overall positive trend with time through the late 1960s, then a roughly level trend thereafter. A break in trend in about 1968 or 1969 is

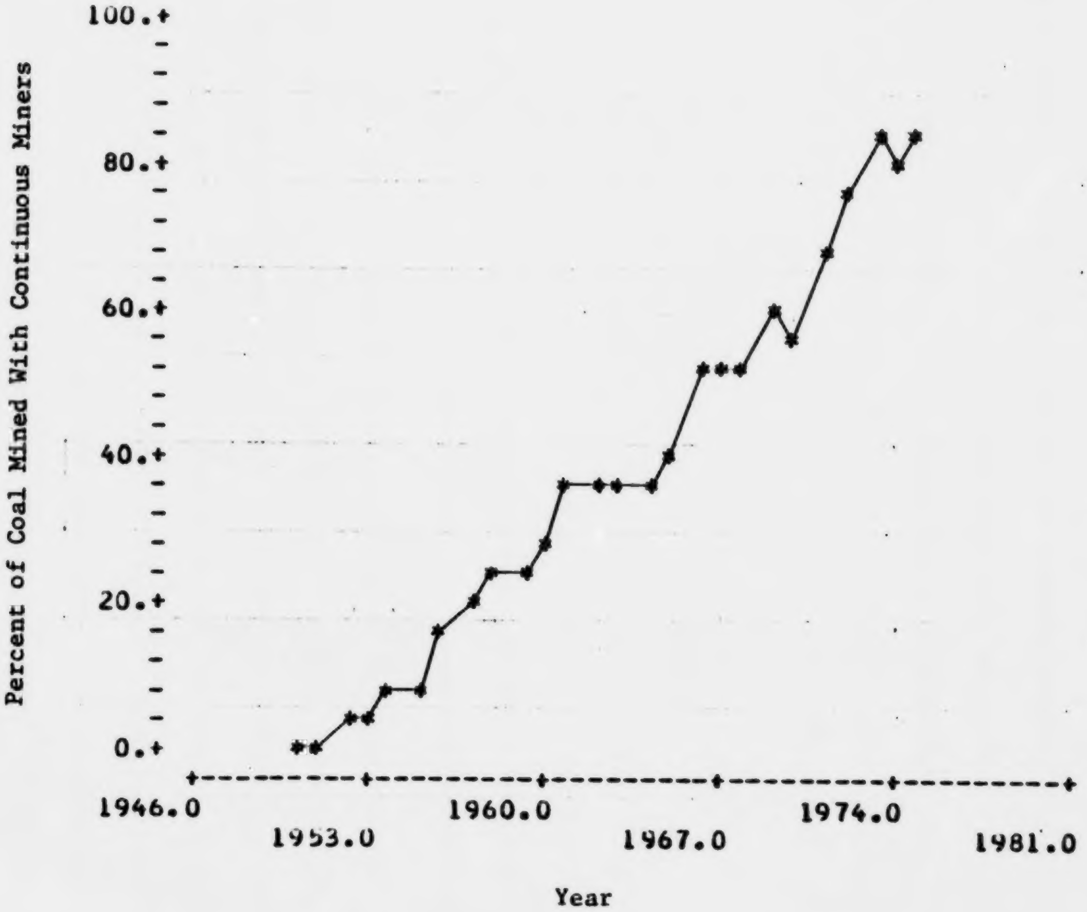


Figure 39. Trend of Percent of Coal Mined With Continuous Miners: Illinois (1950 Through 1975)

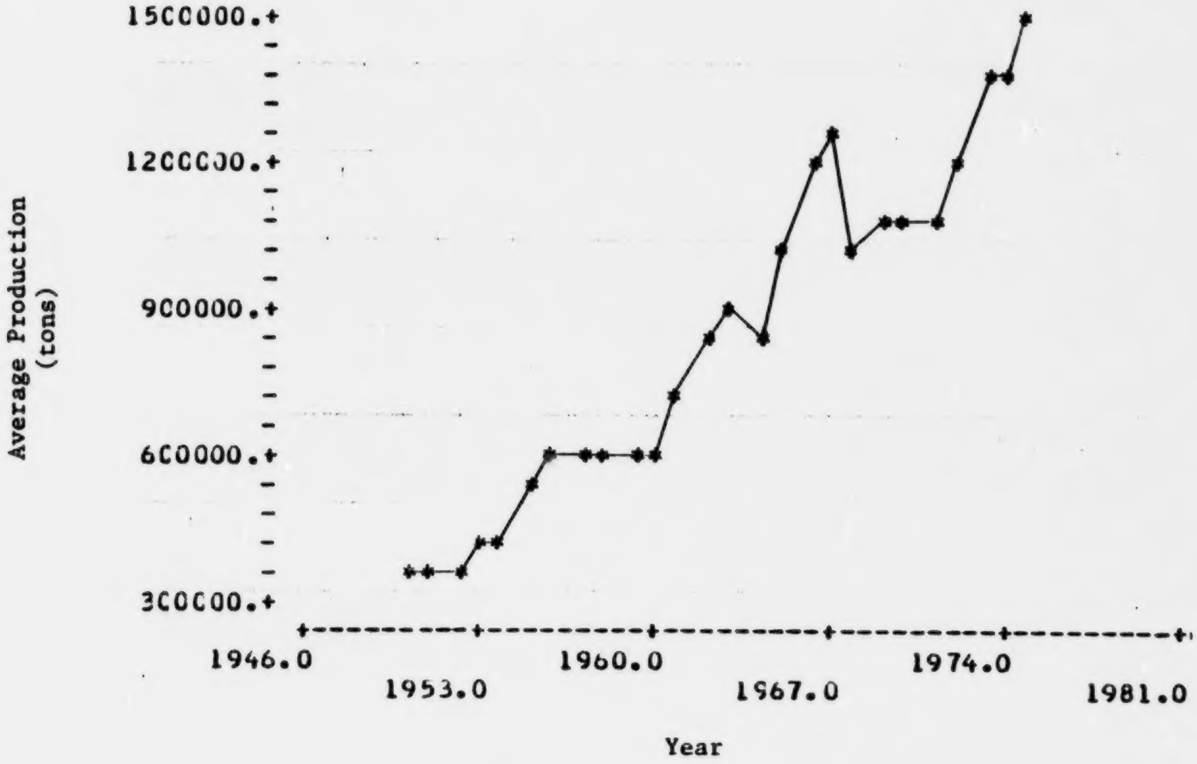


Figure 40. Trend of Average Production: Illinois (1950 Through 1975)

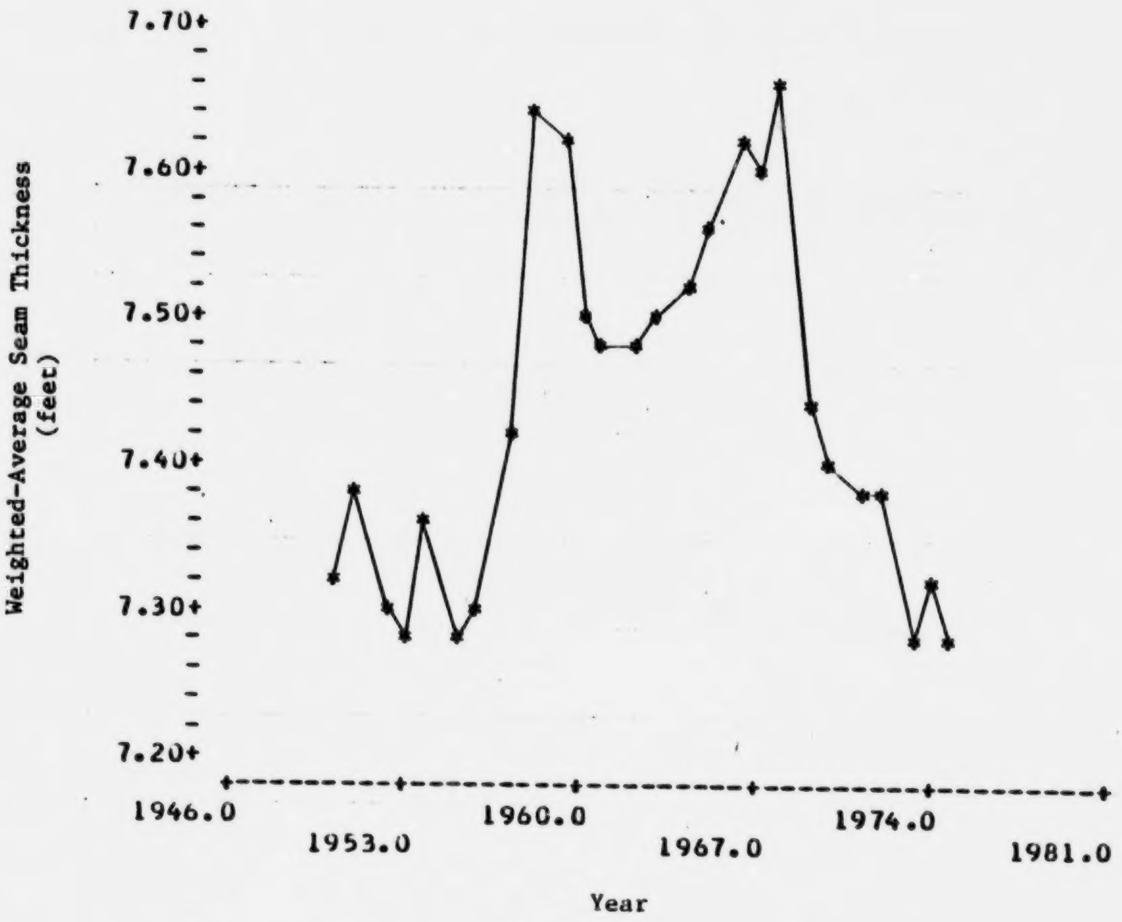


Figure 41. Trend of Weighted-Average Seam Thickness: Illinois (1950 Through 1975)

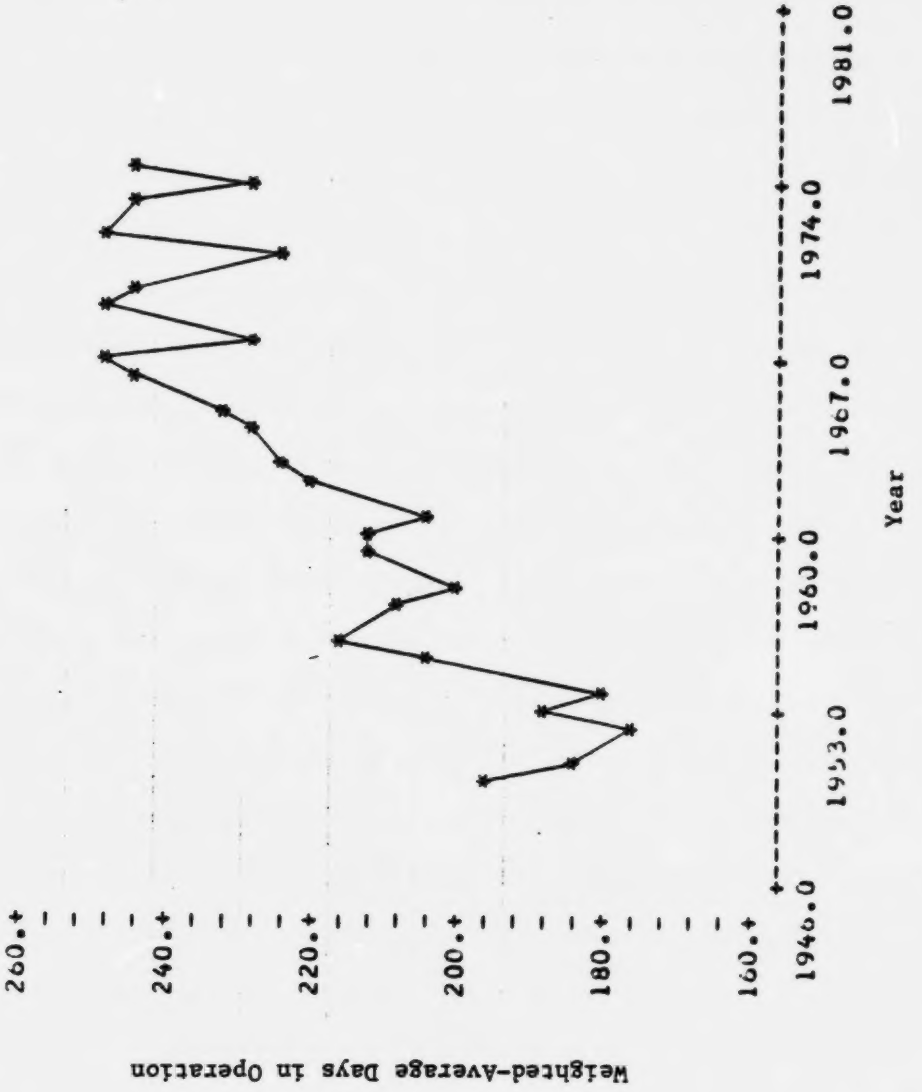


Figure 42. Trend of Weighted-Average Days in Operation: Illinois (1950 Through 1975)

significant (99.0 percent confidence level). The trend was positive before the break and then leveled off in the range of 230 to 240 days.

The actual price of coal (Figure 43) shows a decreasing trend through 1969, then an increasing trend thereafter, with relatively large increases in 1974 and 1975 (99.0 percent confidence level). Under the assumption that there is no Health and Safety Act in 1970 through 1975, the price of coal would have been lower by some amount. Although no direct estimates exist of the impact on the Mine Act on price in Illinois, the average increase in required selling price for five states (32.0 percent) obtained by Fettig (1978) was used as a first approximation. This value produces estimates of values in 1970 through 1973 that appear to be too low for the pre-1970 trend. This is shown in Figure 44. To make a second estimation, three things were noted using "no-Act" price trends from other states: (1) that in other states analyzed, the price in 1971 under the "no-Act" assumption has a tendency to be similar to values in 1968 or 1969, (2) that the 1970 value should be in the overall trend both before and after 1970, and (3) that the 1970 value will probably be lower than the 1969 value. Staying within all of these requirements, a percentage factor of 18.5, which represents the increase in price with the Act over the no-Act price, was applied to the actual price in 1970 and 1971, giving (rounded-off) values of 35.0 and 38.0 cents per million Btu, respectively. This figure of 18.5 percent was obtained by projecting the lowest value for 1970 that would still be in trend with pre-1970 values. This percentage does not appear to be out of line with estimated percentages shown in Table 17, the smallest being 24.93 percent and the largest being 42.56 percent. Values for 1974 and 1975 were obtained by applying the 32.0

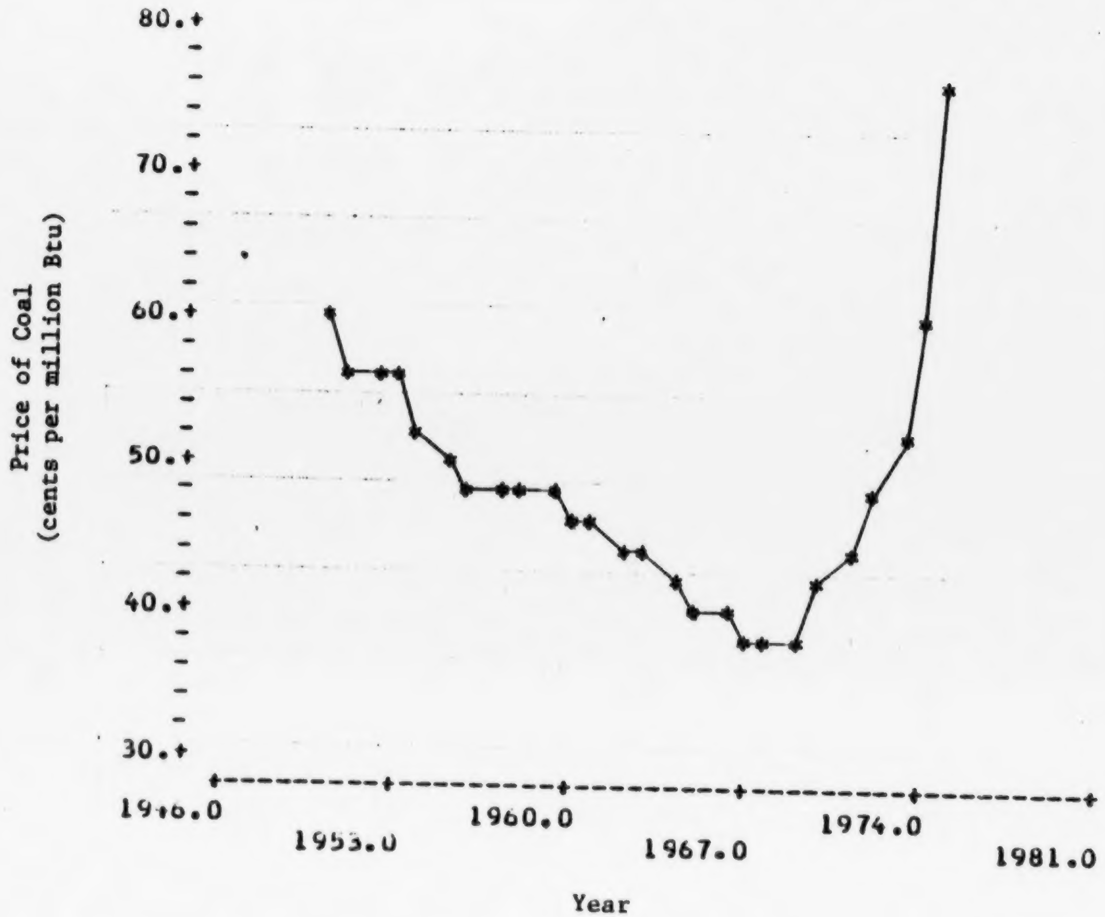


Figure 43. Trend of the Price of Coal: Illinois (1950 Through 1975)

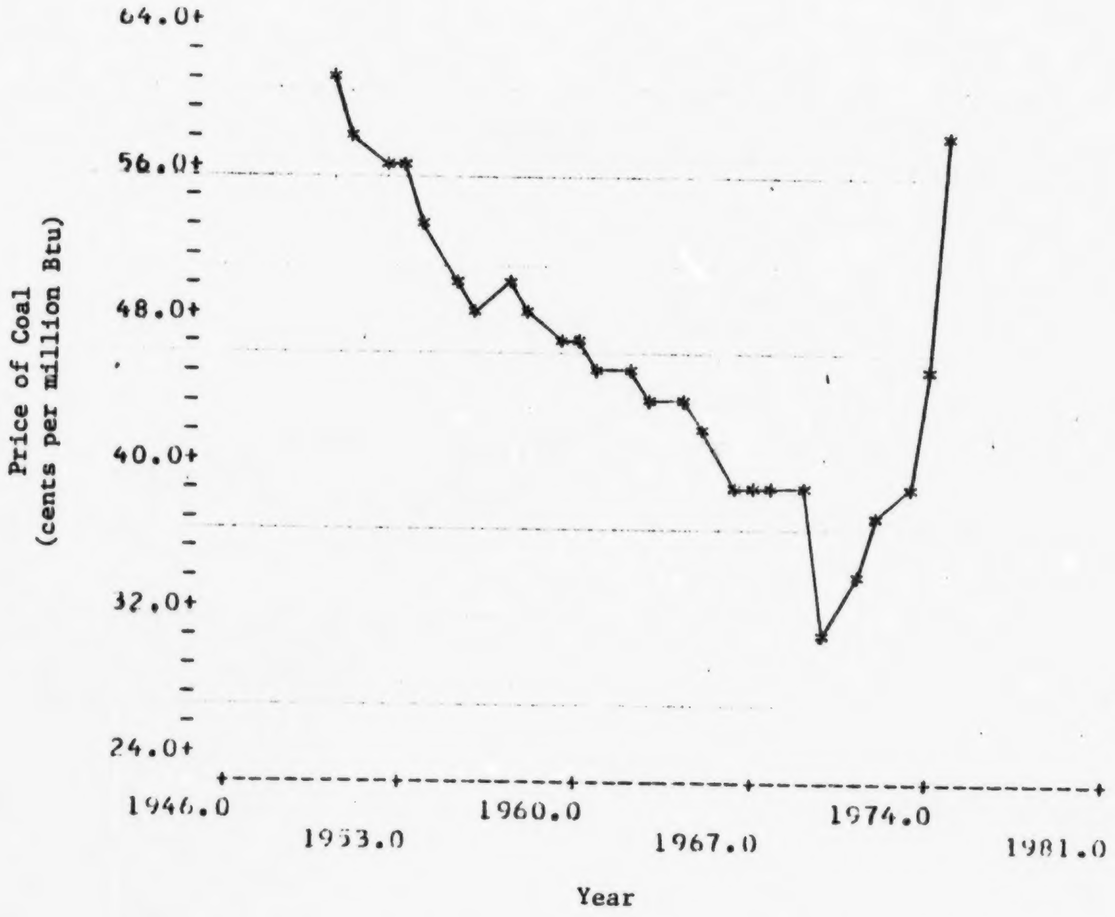


Figure 44. Trend of the Price of Coal Assuming No CMHSA, First Approximation Using 32.0 Percent Factor: Illinois (1950 Through 1975)

percent average figure from Fettig (1978), since there is no reason to suspect that these values were too low. Values for 1972 and 1973 were obtained by applying a percentage of 25.0, the (rounded-off) average of 18.5 and 32.0. The justification for using this approach is that the trend of the price assuming no-Act is made similar to other states that were analyzed by simulation methods (Figure 45). However, obviously, this estimation process is rough and the reader should recognize this in viewing results based on use of these figures.

Results of Regression for 1950 Through 1975

The results for the OLS regression of the model for the years 1950 through 1975 follow.

$$(28)\ PRY_t = \underset{(24.5573)}{-6.969} + \underset{(3.53194)\#}{5.11431}\ AP_t + \underset{(2.91151)}{3.74507}\ ST_t$$

$$\underset{(0.0491225)}{-0.0109471}\ CM_t + \underset{(0.0364252)}{0.0146819}\ DO_t - \underset{(0.0762981)\#\#\#\#\#}{0.243446}\ PR_t$$

$$\underset{(0.0456852)\#}{-0.071642}\ MACT_t$$

$R^2 = 0.8985$

F-statistic (6,19) = 28.0449

Durbin-Watson statistic = 0.7716

Standard error of the regression = 1.29008

Sum of squared residuals = 31.6221.

All variables except MACT and PR are expected to have positive coefficients. The coefficients of PR, MACT, and AP are significant at the 99.5, 90.0, and 90.0 percent confidence levels, respectively, and their signs are as expected. The coefficients of ST, CM, and DO are not significant. The equation is significant at the 99.0 percent confidence level, and almost 90.0 percent of the variance is explained. All

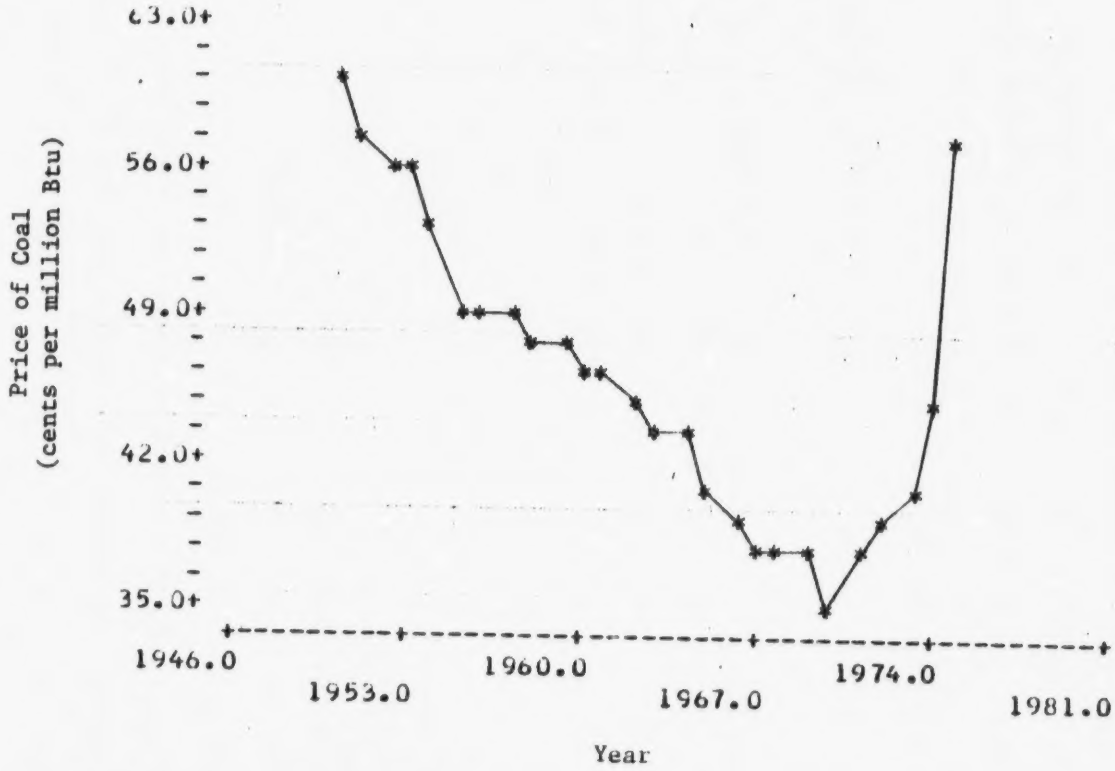


Figure 45. Trend of the Price of Coal Assuming No CMHSA: Illinois (1950 Through 1975)

variables have coefficients with the expected sign except CM, which is not significant. The Durbin-Watson statistic indicates positive autocorrelation (95.0 percent confidence level). The pairwise correlation matrix, Table 18, indicates significant multicollinearity, especially between AP and DO (0.92) and between CM and AP (0.96). A plot of actual and fitted values and a plot of the residuals are presented in Figure 43. The residuals plot gives no indication of the presence of heteroskedasticity.

The Cochrane-Orcutt iterative method was used to correct for the problem of positive autocorrelation. The results follow.

$$(29)\ PRY_t = \underset{(19.0254)}{48.7889} + \underset{(2.57510)}{2.16433}\ AP_t - \underset{(2.26259)}{3.25271}\ ST_t - \underset{(0.0447383)}{0.0296328}\ CM_t$$

$$+ \underset{(0.0179682)}{0.00856842}\ DO_t - \underset{(0.0646583)\#\#\#\#\#}{0.194355}\ PR_t - \underset{(0.0312567)\#}{0.0441209}\ MACT_t$$

$R^2 = 0.9533$

F-statistic (6,18) = 61.3078

Durbin-Watson statistic = 1.5374

Standard error of the regression = 0.822730

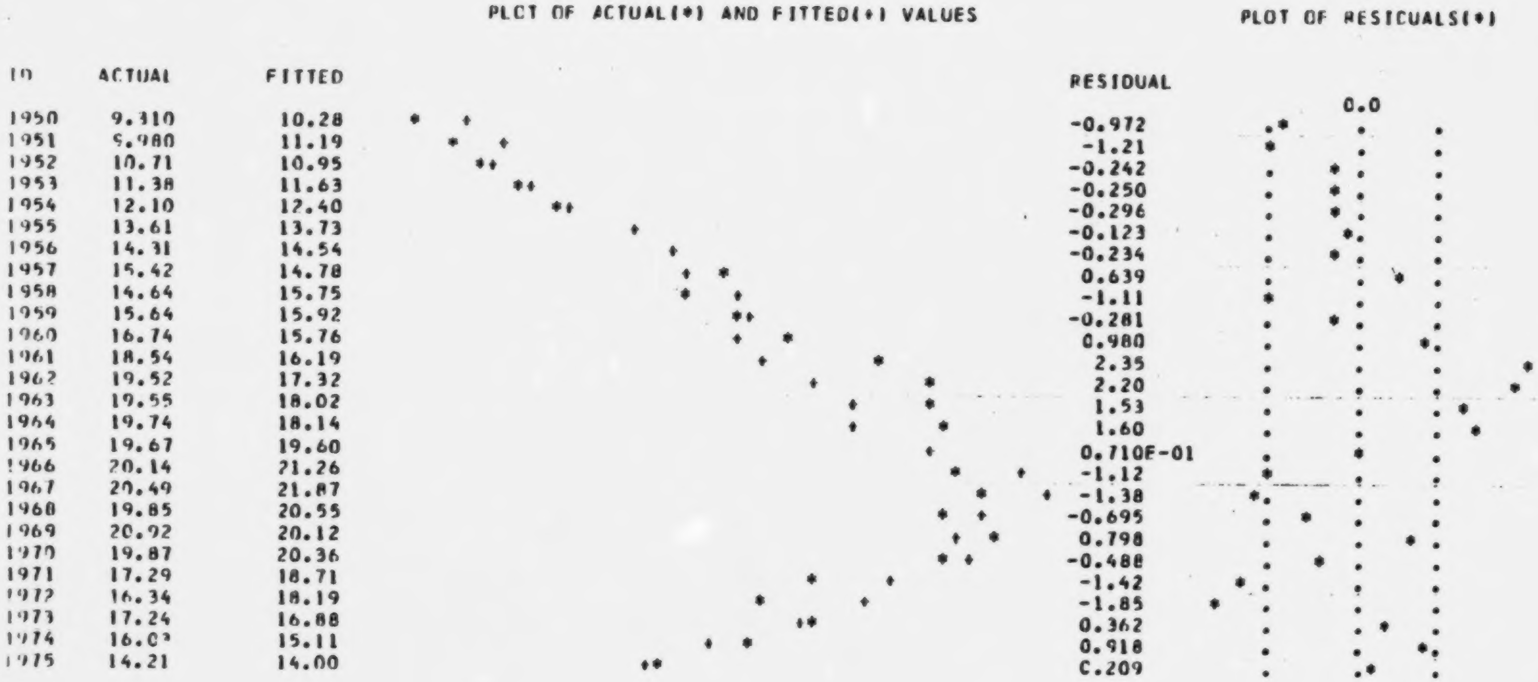
Sum of squared residuals = 12.1839 .

Only the coefficients of PR and MACT are significant at the 99.5 and 90.0 percent confidence level, respectively. The signs of the coefficients are as expected, except for those of ST and CM (both not significant). The F-statistic indicates that the equation is significant at the 99.0 percent confidence level, and over 95.0 percent of the

Table 18

Pairwise Correlation Matrix for AP, ST, CM, DO, PR, and MACT: Illinois (1950 Through 1975)

	AP	ST	CM	DO	PR	MACT
AP	1.0000	0.14081	0.96141	0.91754	-0.64412	0.64919
ST	0.14081	1.0005	0.070985	0.25009	-0.49657	-0.42803
CM	0.96141	0.070985	1.0000	0.86545	-0.64081	0.72563
DO	0.91754	0.25009	0.86545	1.0000	-0.75100	0.42809
PR	-0.64412	-0.49657	-0.64081	-0.75100	1.0000	-0.064269
MACT	0.64919	-0.42803	0.72563	0.42809	-0.064269	1.0000



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                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(*)

ID      ACTUAL       FITTED                                              RESIDUAL
                                                                                              0.0
1950     9.310        10.28                                              -0.972
1951     9.980        11.19                                               -1.21
1952     10.71        10.95                                              -0.242
1953     11.38        11.63                                              -0.250
1954     12.10        12.40                                              -0.296
1955     13.61        13.73                                              -0.123
1956     14.31        14.54                                              -0.234
1957     15.42        14.78                                               0.639
1958     14.64        15.75                                               -1.11
1959     15.64        15.92                                              -0.281
1960     16.74        15.76                                               0.980
1961     18.54        16.19                                                2.35
1962     19.52        17.32                                                2.20
1963     19.55        18.02                                                1.53
1964     19.74        18.14                                                1.60
1965     19.67        19.60                                               0.710E-01
1966     20.14        21.26                                               -1.12
1967     20.49        21.87                                               -1.38
1968     19.85        20.55                                              -0.695
1969     20.92        20.12                                               0.798
1970     19.87        20.36                                              -0.488
1971     17.29        18.71                                               -1.42
1972     16.34        18.19                                               -1.85
1973     17.24        16.88                                               0.362
1974     16.03        15.11                                               0.918
1975     14.21        14.00                                               0.209
```

Figure 46. Plots for Productivity Model, 1950 Through 1975: Illinois (OLS).

variance is explained. The Durbin-Watson statistic is in the inconclusive region, but the Hart-von Neumann test indicates that the problem of positive autocorrelation has been remedied. A plot of actual and fitted values and a plot of the residuals are presented in Figure 47. The residuals plot gives no indication of the presence of heteroskedasticity.

Multicollinearity was corrected for using the principal components method. Average production, weighted-average seam thickness, percent mined by continuous miners, weighted-average days in operation, and price were combined into one variable, PC, using the principal components command in the ESP program. The factor loadings for the principal component and the results of the OLS regression follow.

Variable	Factor Loadings
AP	0.94634
ST	0.34345
CM	0.92414
DO	0.95768
PR	-0.83990

$$\begin{array}{l} \text{(30) } PRY_t = 17.0757 + 3.73219\ PC_t - 0.115945\ MACT_t \\ \qquad\qquad\quad (0.278946)(0.284457)^{****}\ (0.0186280)\#\#\#\#\# \end{array}$$

$R^2 = 0.8822$

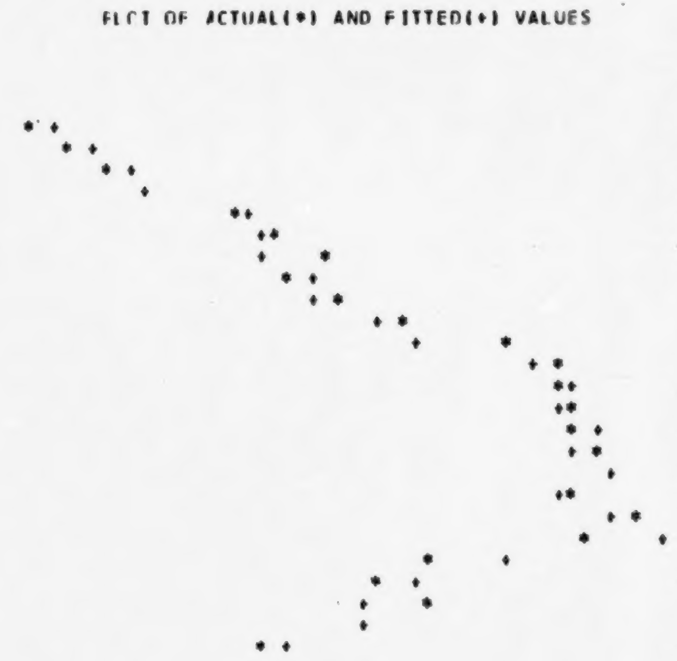
F-statistic (2,23) = 86.0978

Durbin-Watson statistic = 0.8927

Standard error of the regression = 1.26362

Sum of squared residuals = 36.7249.

```
ID      ACTUAL     FITTED     RESIDUAL
1951     9.980      10.47     -0.492
1952    10.71       11.04     -0.332
1953    11.38       11.80     -0.423
1954    12.10       12.14     -0.438E-01
1955    13.61       13.93     -0.318
1956    14.31       14.28      0.329E-01
1957    15.42       14.20      1.22
1958    14.64       14.99     -0.353
1959    15.64       15.17      0.474
1960    16.74       16.33      0.412
1961    18.54       17.05      1.49
1962    19.52       19.04      0.476
1963    19.55       19.68     -0.127
1964    19.74       19.48      0.260
1965    19.67       20.19     -0.520
1966    20.14       19.87      0.275
1967    20.49       20.51     -0.195E-01
1968    19.85       19.54      0.306
1969    20.92       20.52      0.403
1970    19.87       21.38     -1.51
1971    17.29       18.66     -1.37
1972    16.34       16.85     -0.514
1973    17.24       15.93      1.31
1974    16.03       15.97      0.583E-01
1975    14.21       14.73     -0.522
```



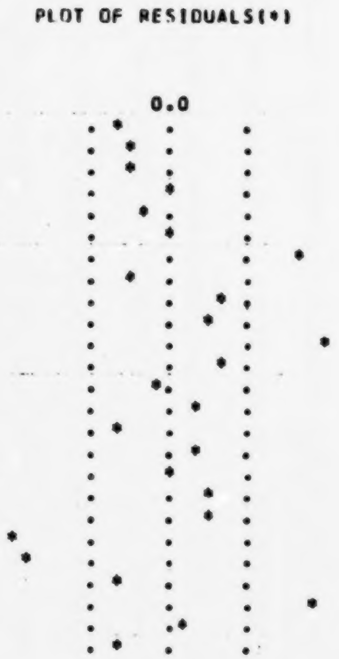


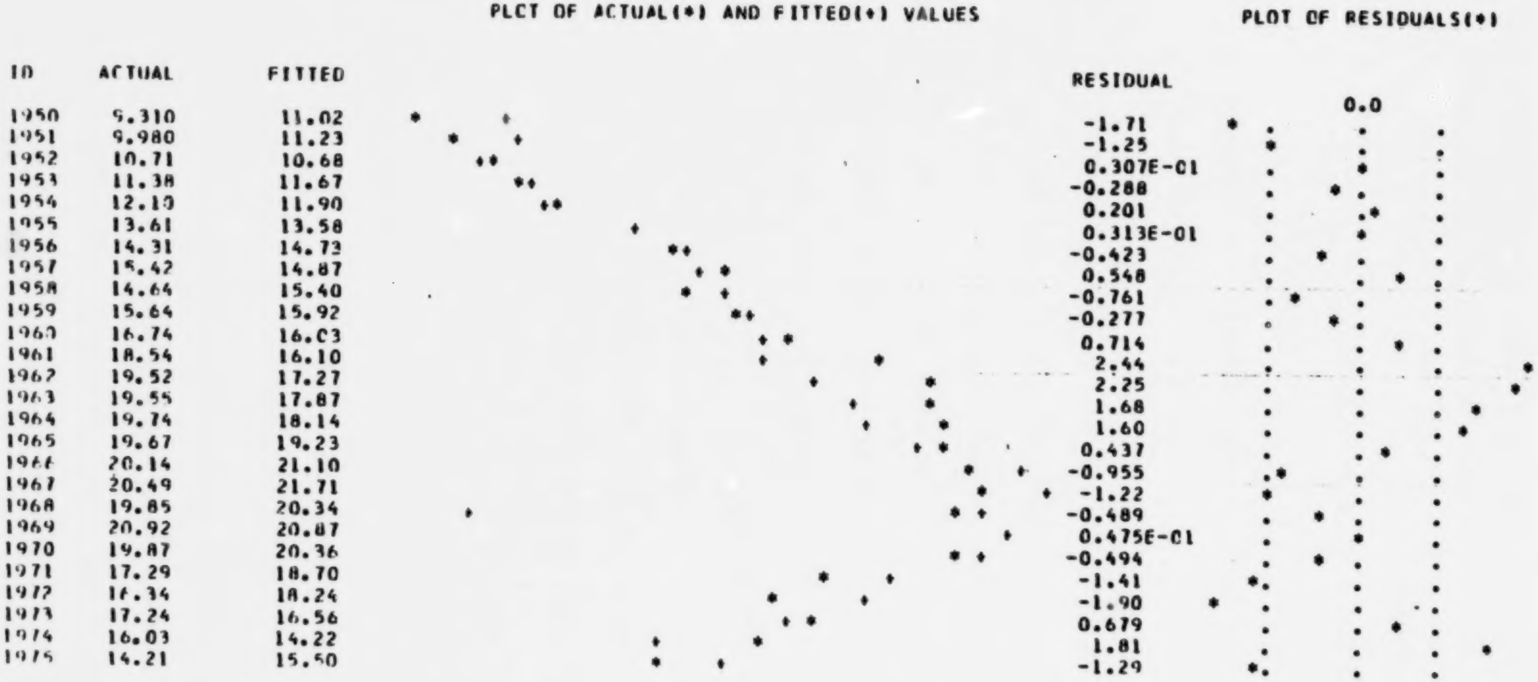
Figure 47. Plots for Productivity Model, 1950 Through 1975: Illinois (CORC).

The coefficient of both the principal component and the Mine-Act variable are significant at the 99.0 and 99.5 percent confidence level, respectively. Since the principal component is composed of variables which are expected to have both positive and negative (price) relations to the dependent variable, the expected sign of the coefficient of the principal component is indeterminate. The Mine-Act variable has the expected sign. The F-statistic indicates that the equation is significant at the 99.0 percent confidence level, and over 88.0 percent of the variance is explained. The Durbin-Watson statistic indicates positive autocorrelation (99.0 percent confidence level). The pairwise correlation matrix below indicates the degree of multicollinearity is low.

	PC	MACT
PC	1.0000	0.45898
MACT	0.45898	1.0000

A plot of actual and fitted values and a plot of the residuals are presented in Figure 48. The residuals plot gives no indication of the presence of heteroskedasticity.

Correcting for both multicollinearity and autocorrelation simultaneously using principal components and the Cochrane-Orcutt iterative method yields the following results:



```
                              PLCT OF ACTUAL(*) AND FITTED(+) VALUES                PLOT OF RESIDUALS(*)
ID      ACTUAL      FITTED                                              RESIDUAL
                                                                                              0.0
1950    9.310       11.02                                               -1.71
1951    9.980       11.23                                               -1.25
1952    10.71       10.68                                               0.307E-01
1953    11.38       11.67                                               -0.288
1954    12.10       11.90                                               0.201
1955    13.61       13.58                                               0.313E-01
1956    14.31       14.73                                               -0.423
1957    15.42       14.87                                               0.548
1958    14.64       15.40                                               -0.761
1959    15.64       15.92                                               -0.277
1960    16.74       16.03                                               0.714
1961    18.54       16.10                                               2.44
1962    19.52       17.27                                               2.25
1963    19.55       17.87                                               1.68
1964    19.74       18.14                                               1.60
1965    19.67       19.23                                               0.437
1966    20.14       21.10                                               -0.955
1967    20.49       21.71                                               -1.22
1968    19.85       20.34                                               -0.489
1969    20.92       20.87                                               0.475E-01
1970    19.87       20.36                                               -0.494
1971    17.29       18.70                                               -1.41
1972    16.34       18.24                                               -1.90
1973    17.24       16.56                                               0.679
1974    16.03       14.22                                               1.81
1975    14.21       15.50                                               -1.29
```

Figure 48. Plots for Productivity Model Using Principal Components, 1950 Through 1975: Illinois (OLS).

$$(31)\ PRY_t = 17.3246 + 1.67814\ PC_t - 0.0513428\ MACT_t$$
$$(1.15490)(0.799022)^{**}\quad(0.0307632)\#$$

$R^2 = 0.9250$

F-statistic (2,22) = 135.589

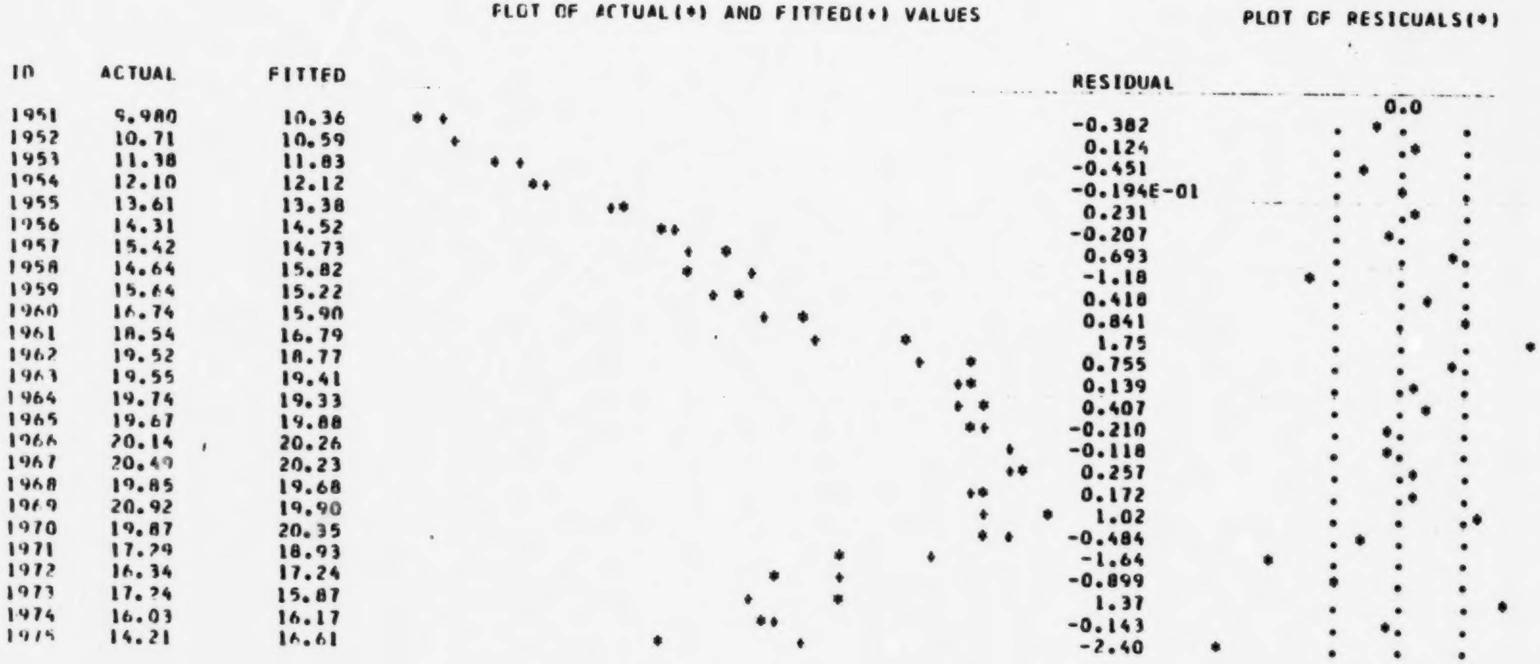
Durbin-Watson statistic = 1.4427

Standard error of the regression = 0.943843

Sum of squared residuals = 19.5985 .

The coefficients of both the principal component and the Mine-Act variable are significant at the 95.0 and 90.0 percent confidence level, respectively. The Durbin-Watson statistic is in the inconclusive region. However, the Hart-von Neumann test indicates no autocorrelation. A plot of actual and fitted values and a plot of the residuals are presented in Figure 49 . The residuals plot gives no indication of the presence of heteroskedasticity.

Examination of the data for weighted-average seam thickness reveals that the maximum is 7.66 feet and the minimum is 7.27; a variation of only 0.39 feet. This small variation is not likely to have a marked effect on productivity, especially in seams this thick. Indeed, the work of Malhotra (1975) and Shields, et al. (1954) indicate that the increase in productivity with seam thickness tends to level off at about 6.5 to 7 feet. For these reasons, it is thought that seam thickness is not a variable affecting the level of productivity achieved in Illinois, despite statistical significance at the 90.0 percent confidence level. Again seam thickness appears essentially constant over the study period. The statistical significance is due to the correlation



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                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID      ACTUAL     FITTED                                      RESIDUAL
                                                                                      0.0
1951     9.980      10.36                                      -0.382
1952    10.71       10.59                                       0.124
1953    11.38       11.83                                      -0.451
1954    12.10       12.12                                      -0.194E-01
1955    13.61       13.38                                       0.231
1956    14.31       14.52                                      -0.207
1957    15.42       14.73                                       0.693
1958    14.64       15.82                                      -1.18
1959    15.64       15.22                                       0.418
1960    16.74       15.90                                       0.841
1961    18.54       16.79                                       1.75
1962    19.52       18.77                                       0.755
1963    19.55       19.41                                       0.139
1964    19.74       19.33                                       0.407
1965    19.67       19.88                                      -0.210
1966    20.14       20.26                                      -0.118
1967    20.49       20.23                                       0.257
1968    19.85       19.68                                       0.172
1969    20.92       19.90                                       1.02
1970    19.87       20.35                                      -0.484
1971    17.29       18.93                                      -1.64
1972    16.34       17.24                                      -0.899
1973    17.24       15.87                                       1.37
1974    16.03       16.17                                      -0.143
1975    14.21       16.61                                      -2.40
```

Figure 49. Plots for Productivity Model Using Principal Components, 1950 Through 1975: Illinois (CORC)

of productivity with seam thickness. But with this small variation, there probably is no cause-effect relationship.

The results for the OLS regression of the model with seam thickness eliminated are:

$$\begin{aligned} (32)\ PRY_t = {} & \underset{(8.17104)}{22.8778} + \underset{(3.49465)\#\#}{6.15059}\ AP_t - \underset{(0.0498611)}{0.00788261}\ CM_t \\ & + \underset{(0.0363106)}{0.00557536}\ DO_t - \underset{(0.0762016)\#\#\#\#\#}{0.261579}\ PR_t - \underset{(0.0407929)\#\#\#}{0.0997001}\ MACT_t \end{aligned}$$

$R^2 = 0.8897$

F-statistic (5,20) = 32.2669

Durbin-Watson statistic = 0.6039

Standard error of the regression = 1.31103

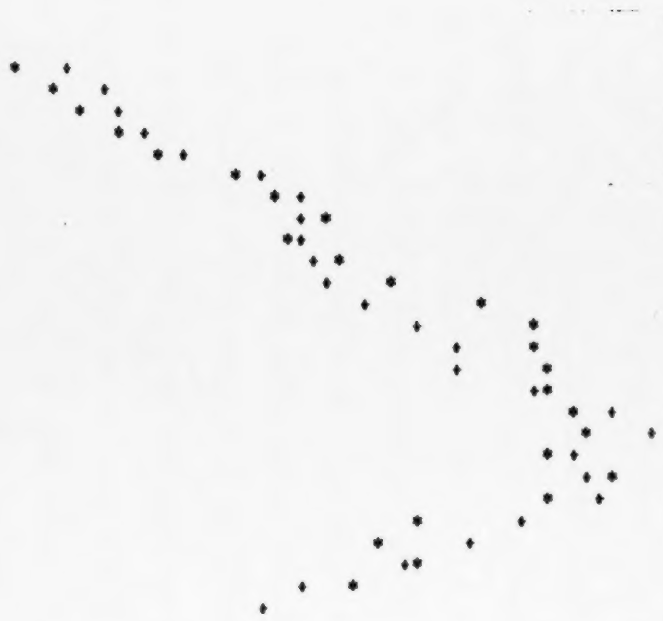
Sum of squared residuals = 34.3758 .

The coefficients of MACT, PR, and AP are significant at the 97.5, 99.5, and 95.0 percent confidence levels, respectively. All variables have the expected sign except CM, which is not significant. The coefficient of DO is also not significant. The equation is significant at the 99.0 percent confidence level, and the percent of variance explained is almost 89.0 percent. The Durbin-Watson statistic indicates positive autocorrelation (99.0 percent confidence level). A plot of actual and fitted values and a plot of the residuals are presented in Figure 50. No sign of heteroskedasticity is evident in the residuals plot.

Correcting for autocorrelation with the Cochrane-Orcutt iterative method yields the following results.

ID	ACTUAL	FITTED	RESIDUAL
1950	9.310	10.25	-0.938
1951	9.980	11.06	-1.08
1952	10.71	11.25	-0.541
1953	11.38	11.98	-0.603
1954	12.10	12.58	-0.482
1955	13.61	14.15	-0.540
1956	14.31	14.88	-0.572
1957	15.42	14.80	0.619
1958	14.64	15.01	-0.371
1959	15.64	15.15	0.487
1960	16.74	15.45	1.29
1961	18.54	16.17	2.37
1962	19.52	17.33	2.19
1963	19.55	18.06	1.49
1964	19.74	17.97	1.77
1965	19.67	19.50	0.166
1966	20.14	21.07	-0.931
1967	20.49	21.79	-1.30
1968	19.85	20.16	-0.311
1969	20.92	20.45	0.465
1970	19.87	20.82	-0.955
1971	17.29	19.30	-2.01
1972	16.34	18.17	-1.83
1973	17.24	16.96	0.283
1974	16.03	14.86	1.17
1975	14.21	14.05	C.160

FLCT OF ACTUAL(*) ANC FITTED(+) VALUES



PLOT OF RESIDUALS(*)

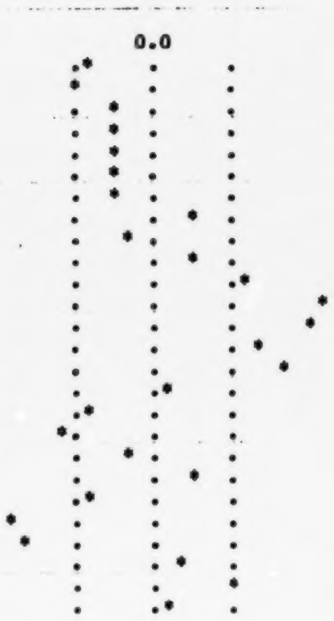


Figure 50. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1975: Illinois (OLS).

$$\begin{aligned} (33)\ PRY_t &= 21.5932 + 2.08048\ AP_t - 0.0244927\ CM_t \\ &\quad (4.35056)(2.66451) \qquad (0.0434486) \\ &\quad + 0.0172772\ DO_t - 0.185661\ PR_t - 0.0386015\ MACT_t \\ &\quad (0.0177174) \qquad (0.0640944)\#\#\#\#\#(0.0315011) \end{aligned}$$

$R^2 = 0.9482$

F-statistic (5,19) = 69.5169

Durbin-Watson statistic = 1.7789

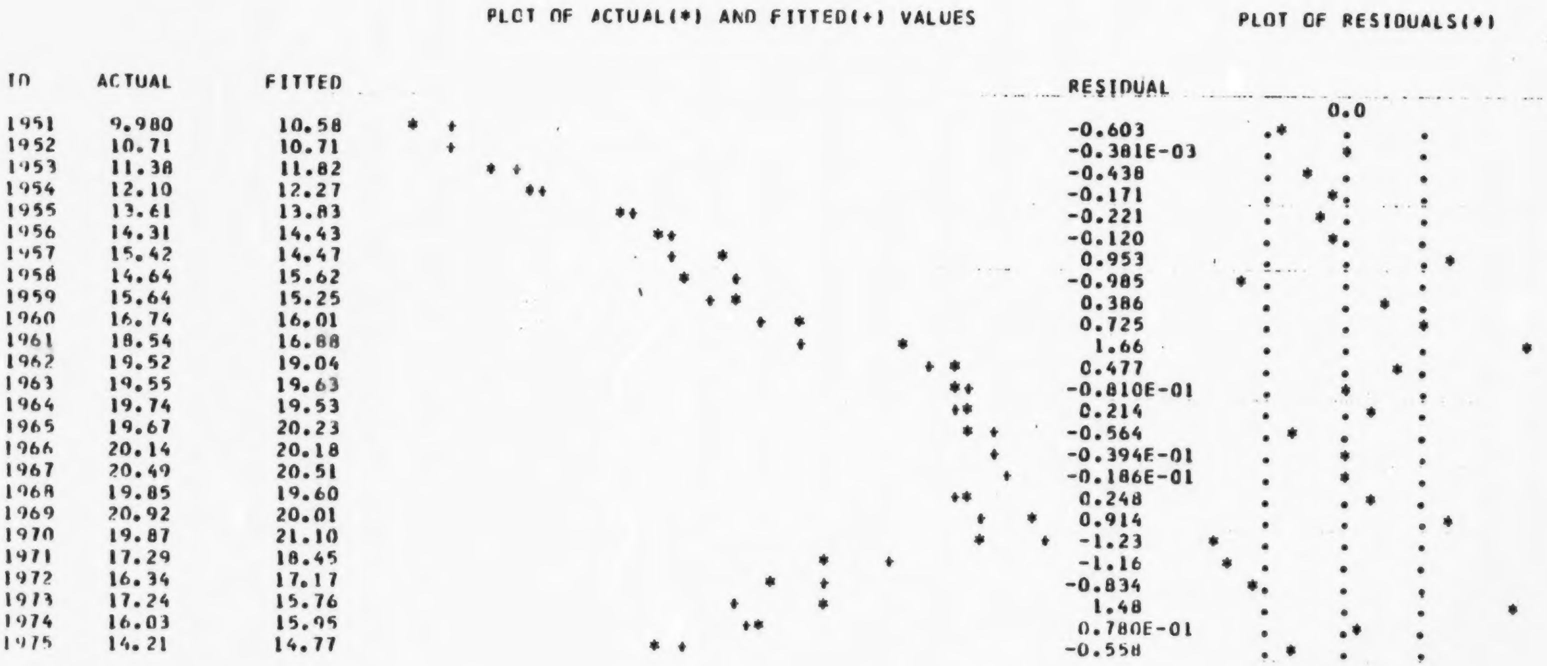
Standard error of the regression = 0.844069

Sum of squared residuals = 13.5366 .

The coefficient of price is significant at the 99.5 percent confidence level. All variables except percent mined by continuous miners, which is not significant, have the expected sign; however, only price is significant. The F-statistic indicates the equation is significant at the 99.0 percent confidence level, and almost 95.0 percent of the variance is explained. The Durbin-Watson statistic is in the inconclusive region, but the Hart-von Neumann test indicates that the positive autocorrelation has been remedied. A plot of actual and fitted values and a plot of the residuals are presented in Figure 51 . The residuals plot does not indicate the presence of heteroskedasticity.

Again, the method of principal components was used to correct for multicollinearity. The factor loadings for the principal component and the results of the OLS regression follow.

Variable	Factor Loadings
AP	0.96261
CM	0.94694
DO	0.96134
PR	-0.81051



```
                           PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                               RESIDUAL
                                                                                          0.0
1951     9.980       10.58                                               -0.603
1952    10.71        10.71                                               -0.381E-03
1953    11.38        11.82                                               -0.438
1954    12.10        12.27                                               -0.171
1955    13.61        13.83                                               -0.221
1956    14.31        14.43                                               -0.120
1957    15.42        14.47                                                0.953
1958    14.64        15.62                                               -0.985
1959    15.64        15.25                                                0.386
1960    16.74        16.01                                                0.725
1961    18.54        16.88                                                1.66
1962    19.52        19.04                                                0.477
1963    19.55        19.63                                               -0.810E-01
1964    19.74        19.53                                                0.214
1965    19.67        20.23                                               -0.564
1966    20.14        20.18                                               -0.394E-01
1967    20.49        20.51                                               -0.186E-01
1968    19.85        19.60                                                0.248
1969    20.92        20.01                                                0.914
1970    19.87        21.10                                               -1.23
1971    17.29        18.45                                               -1.16
1972    16.34        17.17                                               -0.834
1973    17.24        15.76                                                1.48
1974    16.03        15.95                                                0.780E-01
1975    14.21        14.77                                               -0.558
```

Figure 51. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1975: Illinois (CORC).

$$(34)\ PRY_t = 17.2106 + 3.85859\ PC_t - 0.135562\ MACT_t$$
$$(0.29046)(0.311587)****(0.0204046)\#\#\#\#\#$$

$R^2 = 0.8696$

F-statistic (2,23) = 76.7004

Durbin-Watson statistic = 0.8572

Standard error of the regression = 1.32923

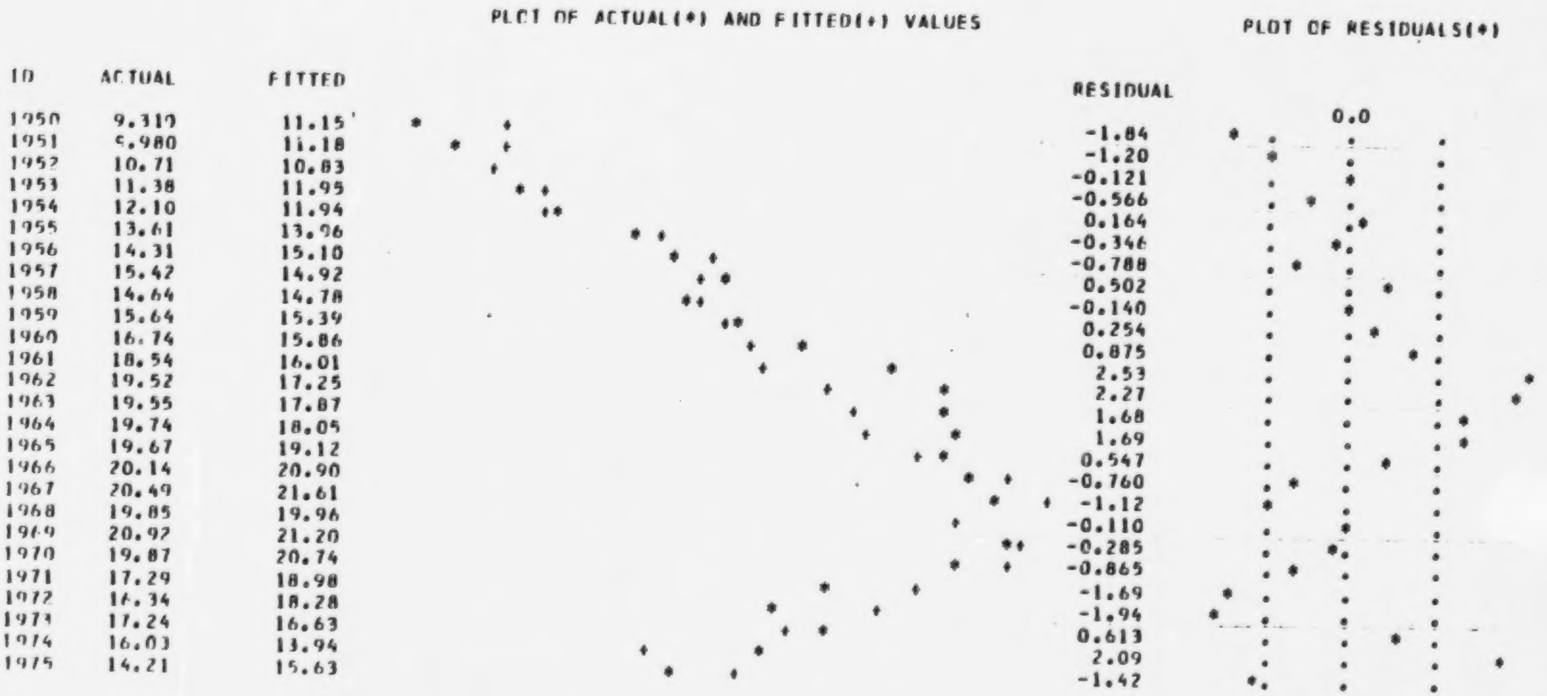
Sum of squared residuals = 40.6378.

The coefficients of the principal component and the Mine-Act variable are both significant at the 99.0 and 99.5 percent confidence level, respectively. The coefficient of the Mine-Act variable has the expected sign. The F-statistic indicates that the equation is significant at the 99.0 percent confidence level, and almost 87.0 percent of the variance is explained. The Durbin-Watson statistic indicates positive autocorrelation (99.0 percent confidence level). The degree of multicollinearity is low, as indicated by the correlation matrix below.

	PC	MACT
PC	1.0000	0.52158
MACT	0.52158	1.0000

A plot of actual and fitted values and a plot of the residuals are presented in Figure 52. The residuals plot gives no indication of the presence of heteroskedasticity.

Correcting for multicollinearity and autocorrelation with both principal components and Cochrane-Orcutt methods yields the following results.



ID	ACTUAL	FITTED	RESIDUAL
1950	9.319	11.15	-1.84
1951	9.980	11.18	-1.20
1952	10.71	10.83	-0.121
1953	11.38	11.95	-0.566
1954	12.10	11.94	0.164
1955	13.61	13.96	-0.346
1956	14.31	15.10	-0.788
1957	15.42	14.92	0.502
1958	14.64	14.78	-0.140
1959	15.64	15.39	0.254
1960	16.74	15.86	0.875
1961	18.54	16.01	2.53
1962	19.52	17.25	2.27
1963	19.55	17.87	1.68
1964	19.74	18.05	1.69
1965	19.67	19.12	0.547
1966	20.14	20.90	-0.760
1967	20.49	21.61	-1.12
1968	19.85	19.96	-0.110
1969	20.92	21.20	-0.285
1970	19.87	20.74	-0.865
1971	17.29	18.98	-1.69
1972	16.34	18.28	-1.94
1973	17.24	16.63	0.613
1974	16.03	13.94	2.09
1975	14.21	15.63	-1.42

Figure 52. Plots for Productivity Model Exluding Seam Thickness Using Principal Components, 1950 Through 1975: Illinois (OLS).

$$(35)\ PRY_t = 17.3732 + 1.66563\ PC_t - 0.0537309\ MACT_t$$
$$(1.20690)(0.753821)^{**}\quad (0.0307966)^{\#\#}$$

$R^2 = 0.9274$

F-statistic (2,22) = 140.527

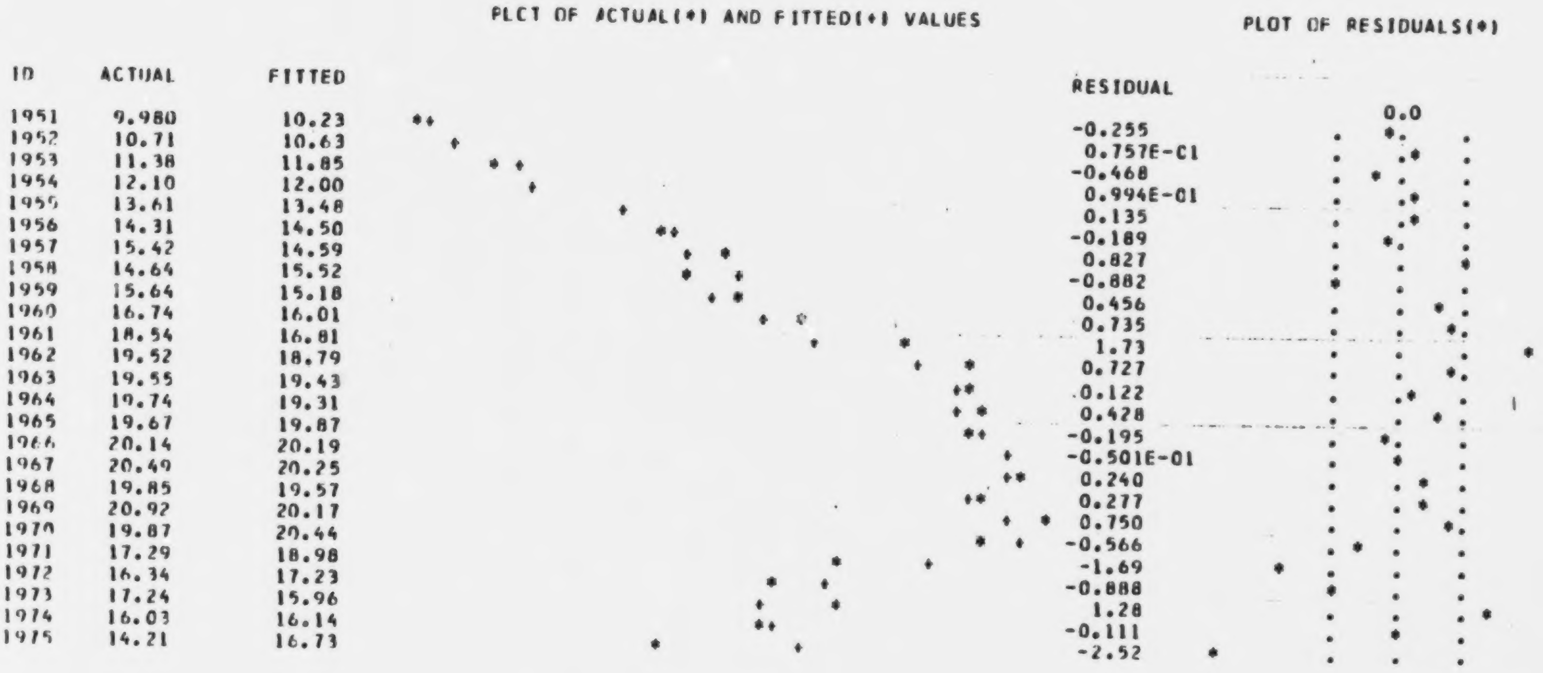
Durbin-Watson statistic = 1.3639

Standard error of the regression = 0.928337

Sum of squared residuals = 18.9598 .

The coefficients of both the principal component and the Mine-Act variable are significant at the 95.0 percent confidence level. The coefficient of MACT has the expected sign. The F-statistic indicates that the equation is significant at the 99.0 percent confidence level, and almost 93.0 percent of the variance is explained. The Durbin-Watson statistic is in the inconclusive region; however, the Hart-von Neumann test indicates that there is positive autocorrelation (95.0 percent confidence level). A plot of actual and fitted values and a plot of the residuals are presented in Figure 53. The residuals plot does not indicate the presence of heteroskedasticity.

A comparison of the results for Equations 4 and 8 indicates that the seam thickness variable is not important. This is because the F-statistic for testing the hypothesis that the coefficient of ST equals zero is only 2.00, less than the critical F(1,18;0.05) value of 4.41.



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                                PLCT OF ACTUAL(*) AND FITTED(+) VALUES            PLOT OF RESIDUALS(*)
ID      ACTUAL      FITTED
                                                                          RESIDUAL
                                                                                         0.0
1951     9.980       10.23                                                -0.255
1952    10.71        10.63                                                 0.757E-C1
1953    11.38        11.85                                                -0.468
1954    12.10        12.00                                                 0.994E-01
1955    13.61        13.48                                                 0.135
1956    14.31        14.50                                                -0.189
1957    15.42        14.59                                                 0.827
1958    14.64        15.52                                                -0.882
1959    15.64        15.18                                                 0.456
1960    16.74        16.01                                                 0.735
1961    18.54        16.81                                                 1.73
1962    19.52        18.79                                                 0.727
1963    19.55        19.43                                                 0.122
1964    19.74        19.31                                                 0.428
1965    19.67        19.87                                                -0.195
1966    20.14        20.19                                                -0.501E-01
1967    20.49        20.25                                                 0.240
1968    19.85        19.57                                                 0.277
1969    20.92        20.17                                                 0.750
1970    19.87        20.44                                                -0.566
1971    17.29        18.98                                                -1.69
1972    16.34        17.23                                                -0.888
1973    17.24        15.96                                                 1.28
1974    16.03        16.14                                                -0.111
1975    14.21        16.73                                                -2.52
```

Figure 53. Plots for Productivity Model Exluding Seam Thickness Using Principal Components, 1950 Through 1975: Illinois (CORC).

Results of Regressions for 1950 Through 1969 and Predictions of Productivity

This section derives predictions of productivity levels that might have been obtained in 1970 through 1975 if the Coal Mine Health and Safety Act of 1969 had not been passed. Predictions are made using three approaches. First, a time trend of productivity from 1950 to 1969 is used to forecast levels in later years; second, regression estimates of the multivariate model were made using data for 1950 through 1969. Predictions were made using values of the independent variables in 1970 through 1975 and compared to actual levels of productivity. Third, predictions are made based on the results of the model for 1950 through 1975 by subtracting the negative influence of MACT on productivity.

It is conceivable that the Mine Act could have some effect on the magnitudes of the independent variables, thus affecting the predictions indirectly. To investigate this possibility for Illinois, the trend of each variable is reexamined for breaks in 1969 using piecewise regression. In Figure 39, the percent of coal mined by continuous miners shows a strongly increasing trend over the whole time period, with no breaks in trend in 1969. No break in trend is evidenced for average production (Figure 40). Theoretically, this mine-size variable could have been affected by the legislation, as described in the section on West Virginia. However, in Illinois, small underground mines were of relatively little importance when the Act was passed, so it would not be expected that the average production would be affected. An examination on mine closings further supports this. Weighted-average seam thickness (Figure 41) shows a decline in trend after 1968 (99.0 percent confidence level). This could hardly be blamed on the Mine Act, especially since the change is so small. Weighted-average days in operation

(Figure 42) shows a significant break in trend in 1968 or 1969 (99.0 percent confidence level). The trend was positive, then leveled off in the range of 230 to 240 days. It is more likely that this change is due to an increase in strikes or perhaps to reaching the "natural" limit than to the Mine Act. The actual price of coal is certain to have been affected by the Mine Act, but this effect has been accounted for by subtracting out the estimated portion of the actual price that was due to the existence of the Act. There is no direct evidence, in this case, supporting the hypothesis that the Mine Act has significant indirect effects on productivity.

Productivity shows a positive trend with time through 1969; after 1969 the trend becomes negative. A simple regression of productivity with time (T) from 1 (1950) through 20 (1969) was run. The results are:

$$(36)\quad PRY_t = \underset{(0.432275)}{9.34421} + \underset{(0.0360856)^{****}}{0.644645\ T}$$

$R^2 = 0.9466$

F-statistic (1,18) = 319.133

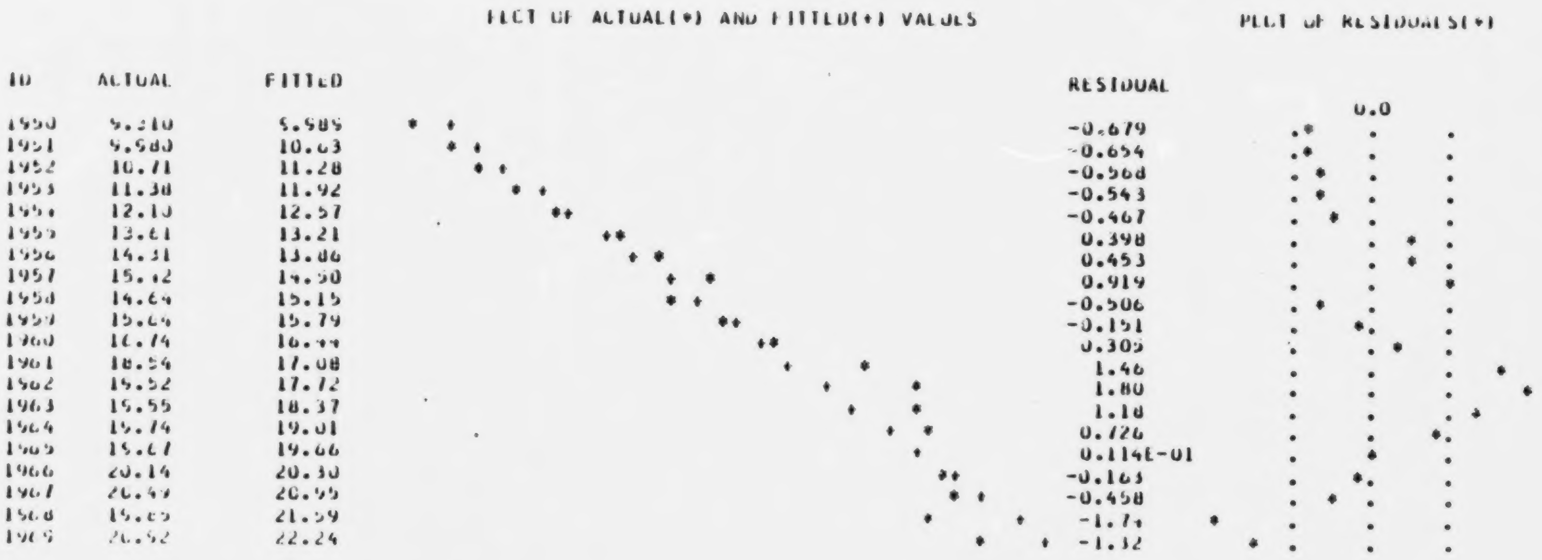
Durbin-Watson statistic = 0.5028

Standard error of the regression = 0.930561

Sum of squared residuals = 15.5870 .

This regression results in positive autocorrelation at the 99.0 percent confidence level (Figure 54).

The Cochrane-Orcutt iterative technique eliminates the autocorrelation and explains over 97.0 percent of the variation in



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ID      ACTUAL      FITTED      RESIDUAL
1950     9.310       9.989      -0.679
1951     9.980      10.63       -0.654
1952    10.71       11.28       -0.568
1953    11.38       11.92       -0.543
1954    12.10       12.57       -0.467
1955    13.61       13.21        0.398
1956    14.31       13.86        0.453
1957    15.42       14.50        0.919
1958    14.64       15.15       -0.506
1959    15.64       15.79       -0.151
1960    16.74       16.44        0.305
1961    18.54       17.08        1.46
1962    19.52       17.72        1.80
1963    19.55       18.37        1.18
1964    19.74       19.01        0.726
1965    19.67       19.66        0.114E-01
1966    20.14       20.30       -0.163
1967    20.49       20.95       -0.458
1968    19.85       21.59       -1.74
1969    20.92       22.24       -1.32
```

Figure 54. Plots for Time Trend of Productivity, 1950 Through 1969: Illinois (OLS).

productivity. The results are:

$$(37)\quad PRY_t = \underset{(1.88392)}{11.2969} + \underset{(0.120538)^{****}}{0.505337}\,T$$

$R^2 = 0.9731$

F-statistic (1,17) = 614.784

Durbin-Watson statistic = 1.8178

Standard error of the regression = 0.620465

Sum of squared residuals = 6.54460.

The residuals and actual and fitted values are plotted in Figure 55. The residuals show no evidence for the presence of heteroskedasticity. Values of productivity were extrapolated for the years 1970 through 1975 using this equation (Table 19). All of these predictions are significantly greater than actual values. The time trend predicts increasing productivity over time, in trend with before 1970.

Similarly, a regression was run for 1950 through 1969 with productivity as a function of average production, weighted-average seam thickness, percent mined by continuous miners, and weighted-average days in operation. The results are:

$$(38)\quad PRY_t = \underset{(28.1398)}{42.4134} + \underset{(3.46891)}{0.767358}\,AP_t - \underset{(3.13042)}{1.41207}\,ST_t$$

$$+ \underset{(0.0664574)}{0.0658740}\,CM_t - \underset{(0.0381251)}{0.00145005}\,DO_t - \underset{(0.161820)\#\#\#}{0.378547}\,PR_t$$

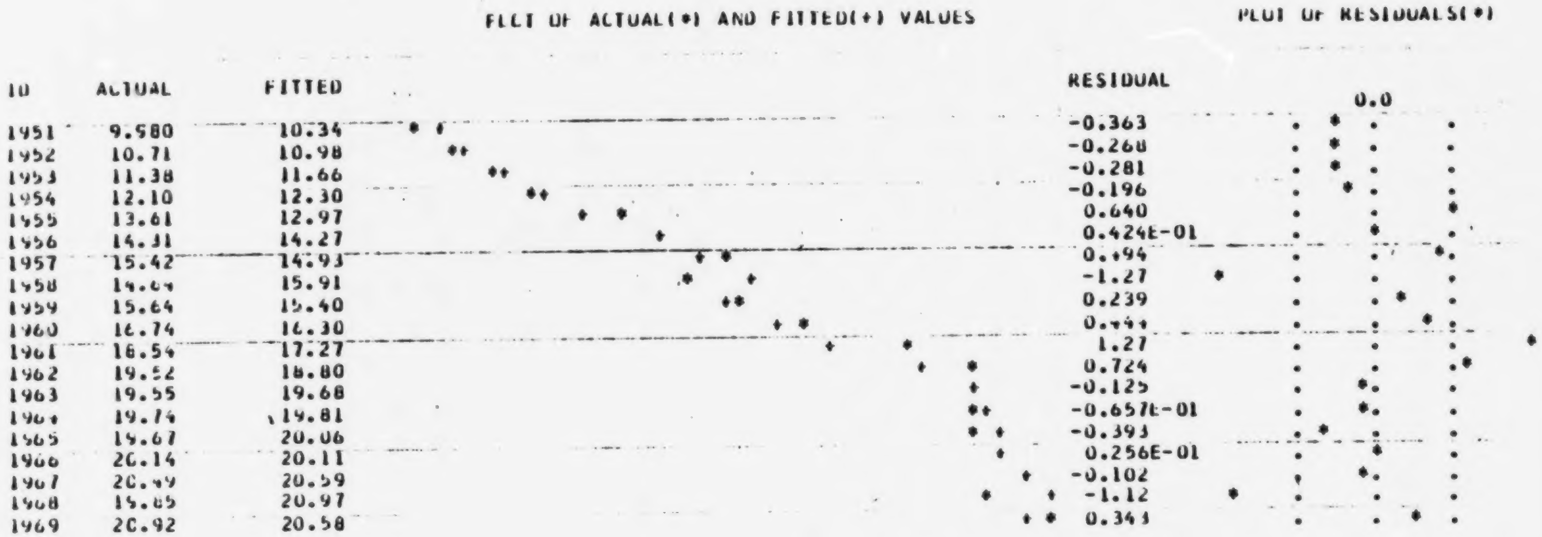
$R^2 = 0.9419$

F-statistic (5,14) = 45.3555

Durbin-Watson statistic = 0.4681

Standard error of the regression = 1.10113

Sum of squared residuals = 16.9747.



ID	ACTUAL	FITTED	RESIDUAL
1951	9.580	10.34	-0.363
1952	10.71	10.98	-0.268
1953	11.38	11.66	-0.281
1954	12.10	12.30	-0.196
1955	13.61	12.97	0.640
1956	14.31	14.27	0.424E-01
1957	15.42	14.93	0.494
1958	14.64	15.91	-1.27
1959	15.64	15.40	0.239
1960	16.74	16.30	0.444
1961	18.54	17.27	1.27
1962	19.52	18.80	0.724
1963	19.55	19.68	-0.125
1964	19.74	19.81	-0.657E-01
1965	19.67	20.06	-0.393
1966	20.14	20.11	0.256E-01
1967	20.49	20.59	-0.102
1968	19.85	20.97	-1.12
1969	20.92	20.58	0.343

Figure 55. Plots for Time Trend of Productivity, 1950 Through 1969: Illinois (CORC).

Table 19

Comparison of Predicted Levels of Productivity Based on a Time Trend and on Multiple Regression With Actual Levels of Productivity in Illinois

	Productivity (tons per man-day)			
Year	Actual	Based on Time Trend (CORC)	Based on AP, ST, CM, DO, and PR (CORC)	Based on AP, ST, CM, DO, and PR derived using 32.0 percent figure for all years (OLS)
1970	19.87	21.91 (±1.59)	22.75 (±3.08)	22.61 (±3.08)
1971	17.29	22.41 (±1.63	23.33 (±3.98	23.18 (±3.98)
1972	16.34	22.92 (±1.68)	23.82 (±4.04)	23.75 (±4.04
1973	17.24	23.42 (±4.72)	24.70 (±5.58)	24.61 (±5.58)
1974	16.03	23.93 (±1.76)	24.63 (±6.98)	24.63 (±6.98)
1975	14.21	24.44 (±1.82)	25.68 (±11.11)	25.68 (±11.11)

Note: Estimated prediction intervals for a 95.0 percent confidence level are given in parentheses.

This regression results in strong positive autocorrelation (99.0 percent confidence level). The pairwise correlation matrix (Table 20) indicates that there are some very high pairwise correlations. Six of these are greater than 90.0 percent. The results are graphed in Figure 56.

The Cochrane-Orcutt iterative technique gives the following results:

$$(39)\quad PRY_t = \underset{(16.1016)}{46.7709} + \underset{(1.76108)}{1.85134}\, AP_t - \underset{(1.61495)^{**}}{3.91803}\, ST_t$$

$$+ \underset{(0.0381575)}{0.0319080}\, CM_t - \underset{(0.0152478)}{0.00103797}\, DO_t + \underset{(0.147591)}{0.0380620}\, PR_t$$

$R^2 = 0.9860$

F-statistic (5,13) = 182.633

Durbin-Watson statistic = 2.0680

Standard error of the regression = 0.512457

Sum of squared residuals = 3.41395.

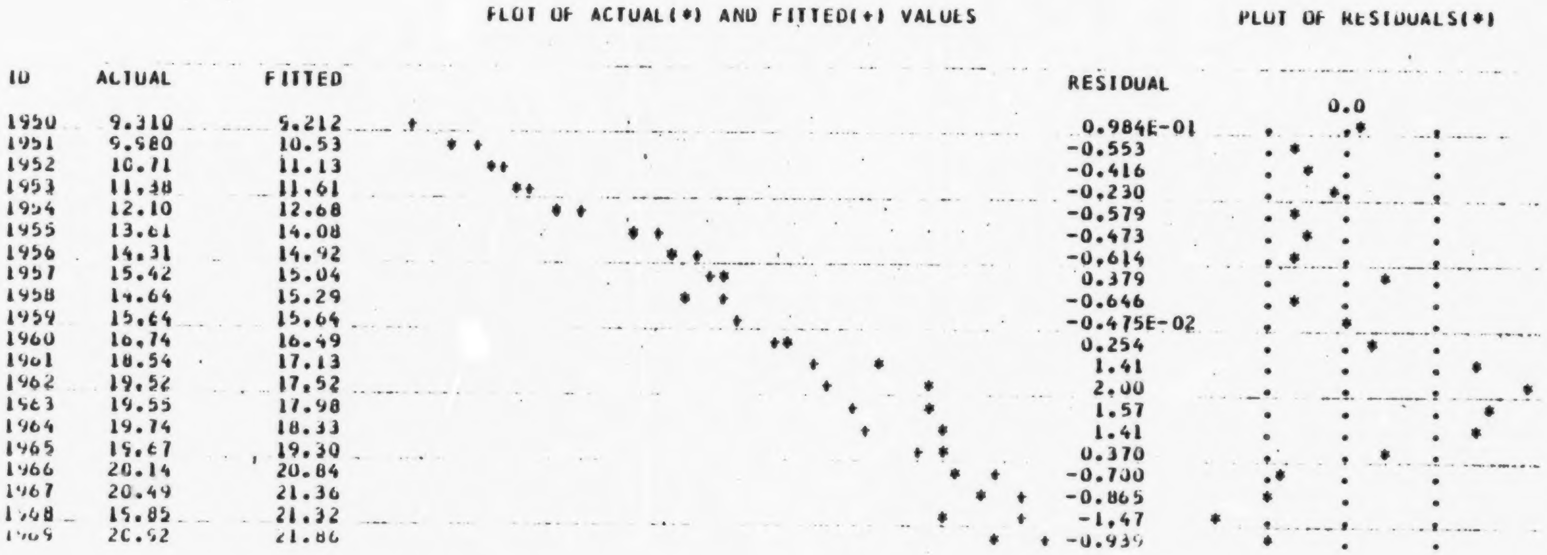
In this case, the Durbin-Watson statistic indicates no autocorrelation. The coefficient of multiple determination is 0.986; however, the only coefficient that is significant at the 90.0 percent confidence level or greater is ST, which has an unexpected negative sign. The lack of significance is not surprising since there is high multicollinearity (refer to Table 20). Residuals and actual and fitted values are shown in Figure 57. The residuals plot shows no evidence of heteroskedasticity.

Values of productivity were extrapolated using this equation and data for the independent variables for 1970 through 1975 (Table 19). The predictions are for increasing productivities that are significantly

Table 20

Pairwise Correlation Matrix for
AP, ST, CM, DO, and PR: Illinois
(1950 Through 1969)

	AP	ST	CM	DO	PR
AP	1.0000	0.69814	0.95116	0.94648	-0.94146
ST	0.69814	1.0004	0.76046	0.61793	-0.74443
CM	0.95116	0.76046	1.0000	0.91889	-0.97046
DO	0.94648	0.61793	0.91889	1.0000	-0.90823
PR	-0.94146	-0.74443	-0.97046	-0.90823	1.0000



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                                   PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(*)

ID      ACTUAL        FITTED                                                    RESIDUAL
                                                                                                      0.0
1950     9.310         9.212                                                     0.984E-01
1951     9.980         10.53                                                    -0.553
1952     10.71         11.13                                                    -0.416
1953     11.38         11.61                                                    -0.230
1954     12.10         12.68                                                    -0.579
1955     13.61         14.08                                                    -0.473
1956     14.31         14.92                                                    -0.614
1957     15.42         15.04                                                     0.379
1958     14.64         15.29                                                    -0.646
1959     15.64         15.64                                                    -0.475E-02
1960     16.74         16.49                                                     0.254
1961     18.54         17.13                                                      1.41
1962     19.52         17.52                                                      2.00
1963     19.55         17.98                                                      1.57
1964     19.74         18.33                                                      1.41
1965     19.67         19.30                                                     0.370
1966     20.14         20.84                                                    -0.700
1967     20.49         21.36                                                    -0.865
1968     19.85         21.32                                                     -1.47
1969     20.92         21.86                                                    -0.939
```
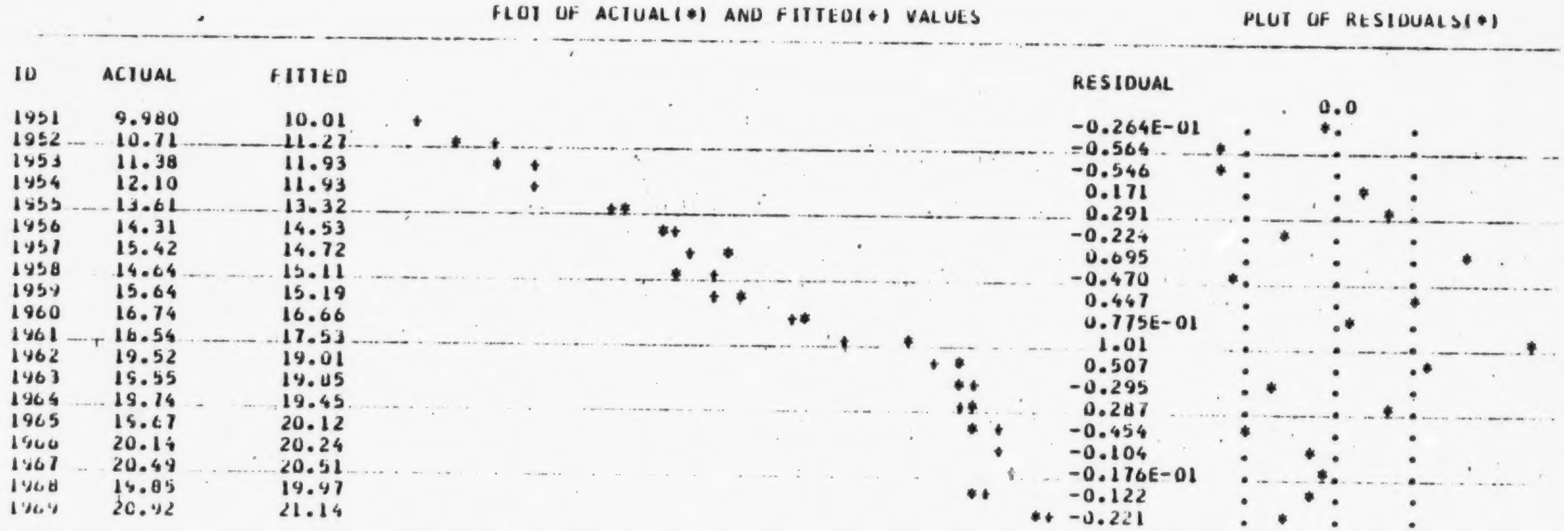

Figure 56. Plots for Productivity Model, 1950 Through 1969: Illinois (OLS).



```
                 FLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLUT OF RESIDUALS(*)

ID      ACTUAL      FITTED                            RESIDUAL
                                                                      0.0
1951     9.980       10.01                            -0.264E-01
1952    10.71        11.27                            -0.564
1953    11.38        11.93                            -0.546
1954    12.10        11.93                             0.171
1955    13.61        13.32                             0.291
1956    14.31        14.53                            -0.224
1957    15.42        14.72                             0.695
1958    14.64        15.11                            -0.470
1959    15.64        15.19                             0.447
1960    16.74        16.66                             0.775E-01
1961    16.54        17.53                             1.01
1962    19.52        19.01                             0.507
1963    19.55        19.05                            -0.295
1964    19.74        19.45                             0.287
1965    19.67        20.12                            -0.454
1966    20.14        20.24                            -0.104
1967    20.49        20.51                            -0.176E-01
1968    19.85        19.97                            -0.122
1969    20.92        21.14                            -0.221
```

Figure 57. Plots for Productivity Model, 1950 Through 1969: Illinois (CORC).

higher than actual values except in 1970. These predictions and those based on the time trend have 95.0 percent confidence intervals that overlap. Predictions are also made assuming that the price with no-Act is decreased by 32.0 percent in all years. This makes little difference in the results.

Using the results of the model for 1950 through 1975, predictions of productivity without the Mine Act were made by adding the amount of productivity lost due to the Mine Act to the prediction of productivity. These predictions, shown in Table 21, are for declining productivities from 1970 through 1975. For comparison, the effects of changes in price on productivity are shown in Table 21, Except for 1975, the Mine Act had a greater negative influence on productivity. Percentage losses in productivity due to MACT are shown in Table 22. The results indicate that productivity was down by around nine percent in 1975 due to the Mine Act.

Summary

Some of the results of regressions are summarized in Tables 23 and 24. The relationships of the independent variables to productivity in the model using data for 1950 through 1975 may be summarized as follows: (1) average production is positively related and is not significant; (2) weighted-average seam thickness is negatively related but is not significant; (3) percent of coal mined by continuous miners is negatively related but not significant; (4) weighted average days in operation is positively related but not significant; (5) price is negatively related and significant; and (6) the Mine-Act variable is negatively related and significant in all equations except 33.

Table 21

Effect of MACT and PR on Productivity: Illinois[*]

Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	Tons Per Man-Day (3) Reduction in Productivity Caused by MACT -((1) x (2))			(4) Prediction of Productivity from Model (95.0 percent confidence level)	(5) Prediction of Productivity Without MACT (4) + (3)			(6) Actual Productivity
		Mean			Low	Mean	High		Low	Mean	High	
1969	-0.105	-0.039	0.027	0				20.01				20.92
1970				5.15924	-0.14	0.20	0.54	21.10	20.96	21.30	2[illegible].64	19.87
1971				10.4678	-0.28	0.41	1.10	18.45	18.17	18.86	1[illegible].55	17.29
1972				29.2330	-0.79	1.14	3.07	17.17	16.89	18.31	2[illegible].24	16.34
1973				42.6833	-1.15	1.66	4.48	15.76	14.61	17.42	2[illegible].24	17.24
1974				52.0947	-1.41	2.03	5.47	15.95	14.54	17.98	[illegible]1.42	16.03
1975				39.1479	-1.06	1.53	4.11	14.77	13.71	16.30	1[illegible].88	14.21

Year	(7) 95.0 Percent Confidence Interval for Coefficient of PR			Cents Per Million Btu (8) Value of PR	(9) Change in PR From 1969	Tons Per Man-Day (10) Reduction in Productivity Caused by Change in PR -((7) x (9))		
		Mean				Low	Mean	High
1969	-0.320	-0.186	-0.052	38.1				
1970				35.0	-3.1	-0.16	-0.58	-0.99
1971				38.0	-0.1	-0.01	-0.02	-0.03
1972				38.5	0.4	0.02	0.07	0.13
1973				41.0	2.9	0.15	0.54	0.93
1974				45.1	7.0	0.36	1.30	2.24
1975				57.2	19.1	0.99	3.55	6.11

[*] Using results of Equation 33.

Table 22

Percentage Losses in Productivity Due to the Mine Act in Illinois

Year	Using Predictions of Regression 33 (data through 1975) (percentage loss)
1970	0.9
1971	2.2
1972	6.2
1973	9.5
1974	11.3
1975	9.4
Average Per Year	6.6

Table 23

Results of Regressions Summary for Illinois

Equation	Constant	AP	ST	CM	DO	PR	MACT	PC	T(Year)	R^2	S	SSR	Autocorrelation (Durbin-Watson Statistic)	F-Statistic
									1950 Through 1975					
28(OLS)	-6.969	5.114 \#	3.745	-0.011	0.015	-0.243 \#\#\#\#\#	-0.072 \#\#			0.90	1.29	31.62	+(0.77)	$28.04_{(6,19)}$
29(CORC)	48.789	2.164	-3.253	-0.030	0.009	-0.194 \#\#\#\#\#	-0.044 \#			0.95	0.82	12.18	None (1.54)	$61.31_{(6,18)}$
30(OLS)	17.076						-0.116 \#\#\#\#\#	3.732 ****		0.88	1.26	36.72	+(0.89)	$86.10_{(2,23)}$
31(CORC)	17.325						-0.051 \#	1.678 **		0.93	0.94	19.60	None (1.44)	$135.59_{(2,22)}$
32(OLS)	22.878	6.151 \#\#		-0.008	0.006	-0.262 \#\#\#\#\#	-0.100 \#\#\#			0.89	1.31	34.38	+(0.60)	$32.27_{(5,20)}$
33(CORC)	21.593	2.080		-0.024	0.017	-0.186 \#\#\#\#\#	-0.039			0.95	0.84	13.54	None (1.78)	$69.52_{(5,19)}$
34(OLS)	17.211						-0.136 \#\#\#\#\#	3.859 ****		0.87	1.33	40.64	+(0.86)	$76.70_{(2,23)}$
35(CORC)	17.373						-0.054 \#\#	1.666 **		0.93	0.93	18.96	+(1.36)	$140.53_{(2,22)}$
									1950 Through 1969					
36(OLS)	9.344								0.645 ****	0.95	0.93	15.59	+(0.50)	$319.13_{(1,18)}$
37(CORC)	11.297								0.505 ****	0.97	0.62	6.54	None (1.82)	$614.78_{(1,17)}$
38(OLS)	42.413	0.767	-1.412	0.066	-0.001	-0.379 \#\#\#				0.94	1.10	16.97	+(0.47)	$45.36_{(5,14)}$
39(CORC)	46.771	1.851	-3.918 **	0.032	-0.001	0.038				0.99	0.51	3.41	None (2.07)	$182.63_{(5,13)}$

Significance Levels:

**	Significant at 95.0 percent confidence level (two-tail test)
****	Significant at 99.0 percent confidence level (two-tail test)
#	Significant at 90.0 percent confidence level (one-tail test)
##	Significant at 95.0 percent confidence level (one-tail test)
###	Significant at 97.5 percent confidence level (one-tail test)
#####	Significant at 91.5 percent confidence level (one-tail test)

Table 24

Ninety-five Percent Confidence Intervals for Coefficients in Illinois Regressions

Equation	AP		ST		CM		DO		PR		MACT		PC		T(Year)	
1950 Through 1975																
3(OLS)	-2.28	12.51	-2.35	9.84	-0.11	0.09	-0.06	0.09	-0.40	-0.08	-0.17	0.02				
4(CORC)	-3.25	7.57	-8.01	1.50	-0.12	0.06	-0.03	0.05	-0.33	-0.06	-0.11	0.02				
5(OLS)											-0.15	-0.08	3.14	4.32		
6(CORC)											-0.11	0.01	0.02	3.34		
7(OLS)	-1.14	13.44			-0.11	0.10	-0.07	0.08	-0.42	-0.10	-0.18	-0.01				
8(CORC)	-3.50	7.66			-0.11	0.07	-0.02	0.05	-0.32	-0.05	-0.10	0.03				
9(OLS)											-0.18	-0.09	3.21	4.50		
10(CORC)											-0.12	0.01	0.10	3.23		
1950 Through 1969																
11(OLS)															0.57	0.72
12(CORC)															0.25	0.76
13(OLS)	-6.67	8.21	-8.13	5.30	-0.08	0.21	-0.08	0.08	-0.73	-0.03						
14(CORC)	-1.95	5.65	-7.41	-0.43	-0.05	0.11	-0.03	0.03	-0.28	0.36						

The regression analyses indicate that the effects of each independent variable on productivity in terms of approximate magnitude are : (1) an increase in average production of 0.1 million tons increases productivity by 0.2 tons per man-day; (2) an increase in weighted-average seam thickness of 1.0 inch decreases productivity by 0.3 tons per man-day; (3) an increase in percent mined by continuous miners of 1.0 decreases productivity by 0.02 tons per man-day; (4) an increase in weighted-average days in operation of 10.0 increases productivity by 0.2 tons per man-day; (5) an increase in price of 1.0 cent per million Btu decreases productivity by 0.2 tons per man-day; and (6) an increase in act enforcement as approximated by a rise in inspections per mine by 10.0 decreases productivity by 0.4 tons per man-day.

The results of these regressions for Illinois indicate that the Mine Act was responsible for losses in productivity in 1970 through 1975 of approximately 1, 2, 6, 10, 11, and 9 percent, respectively.

Ohio

Data and Trends of Variables

The data used for Ohio are presented in Table 25. The state data on productivity (derived from figures on employment, days in operation, and tonnage), days in operation, and average production were obtained from the Ohio Division of Mines Reports for 1950 through 1975. Seam thickness data were available in these reports for 1965 through 1975. Other data sources are as given in the section on methods of investigation.

The trend of productivity in Ohio for the years 1950 through 1975 is shown in Figure 58. There was a steady increase from 1950 (6.81 tons per man-day) through 1969 (20.44 tons per man-day) (Table 25). In the years 1950 through 1955; the total increase in productivity was 44.1 percent, in 1955 through 1960, the percentage increase was 18.9; during 1960 through 1965, the increase was 41.1 percent; and from 1965 through 1969, productivity continued to increase by a total of 24.3 percent. In 1969, the trend changed from positive to negative; the overall decrease in productivity from 1969 through 1975 was 60.4 percent; in 1975, the level had dropped to 8.10 tons per man-day, similar to average productivities attained in 1954.

Using piecewise regression, it was found that the change in the trend of productivity with time since the 1969 Coal Mine Health and Safety Act took effect is statistically significant at the 99.0 percent confidence level. The results for this regression using a join point of 20 (1969) are:

$$\text{(40)}\quad \begin{array}{l} PRY_t = \underset{(0.510)}{5.033} + \underset{(0.0406)^{****}}{0.7225\, X_1} - \underset{(0.181)^{****}}{2.731\, X_2}\,(X_1-20) \end{array}$$

Table 25

Ohio Data

Year	Productivity PRY (tons per man-day)	Average Production AP^a (tons)	Weighted-Average Seam Thickness ST (inches)	Percent Mined by Continuous Miners CM (percent)	Weighted-Average Days in Operation DO	Actual Price of Coal, 1975 Dollars PR_A (cents per million Btu)	Price of Coal Under the Assumption of No-Act, 1975 Dollars PR (cents per million Btu)	Number of Inspections Per Mine Under CMHSA MACT
1950	6.81	47347.9	49.37	2.55	187	53.3	53.3	0.0
1951	6.88	59392.2	49.64	3.99	214	50.9	50.9	0.0
1952	7.56	56185.2	49.63	6.23	204	50.0	50.0	0.0
1953	7.98	61214.8	48.90	9.73	217	50.1	50.1	0.0
1954	8.68	47946.4	49.77	10.75	201	47.7	47.7	0.0
1955	9.81	75382.8	49.87	11.57	219	44.2	44.2	0.0
1956	10.05	82638.8	49.88	14.96	233	45.1	45.1	0.0
1957	10.61	71833.6	50.30	28.35	212	45.4	45.4	0.0
1958	10.84	65967.3	49.98	32.07	208	45.2	45.2	0.0
1959	11.58	65474.3	50.10	29.54	204	43.1	43.1	0.0
1960	11.66	75703.3	50.27	32.42	206	41.9	41.9	0.0
1961	12.87	79577.4	50.29	36.27	210	41.1	41.1	0.0
1962	13.89	91820.4	50.26	38.31	211	40.2	40.2	0.0
1963	14.84	108805.0	50.36	38.70	221	39.1	39.1	0.0
1964	14.81	114609.0	50.44	42.06	218	38.1	38.1	0.0
1965	16.45	145612.0	60.28	45.88	222	37.5	37.5	0.0
1966	17.93	157106.0	57.82	53.06	227	37.1	37.1	0.0
1967	19.12	269975.0	58.13	55.97	238	36.2	36.2	0.0
1968	21.16	332941.0	58.56	57.99	228	35.4	35.4	0.0
1969	20.44	530308.0	58.39	55.10	237	35.6	35.6	0.0
1970	18.55	629936.0	59.17	58.39	245	40.5	31.1	5.15924
1971	12.13	453322.0	57.93	58.12	203	46.2	35.5	10.4678
1972	12.47	581546.0	58.78	64.96	235	48.1	37.0	29.2330
1973	11.86	673547.0	59.4	67.38	233	51.3	39.4	42.6833
1974	10.02	575932.0	58.04	66.36	210	87.3	67.1	52.0947
1975	8.10	508604.0	56.93	65.65	224	95.2	73.2	39.1479

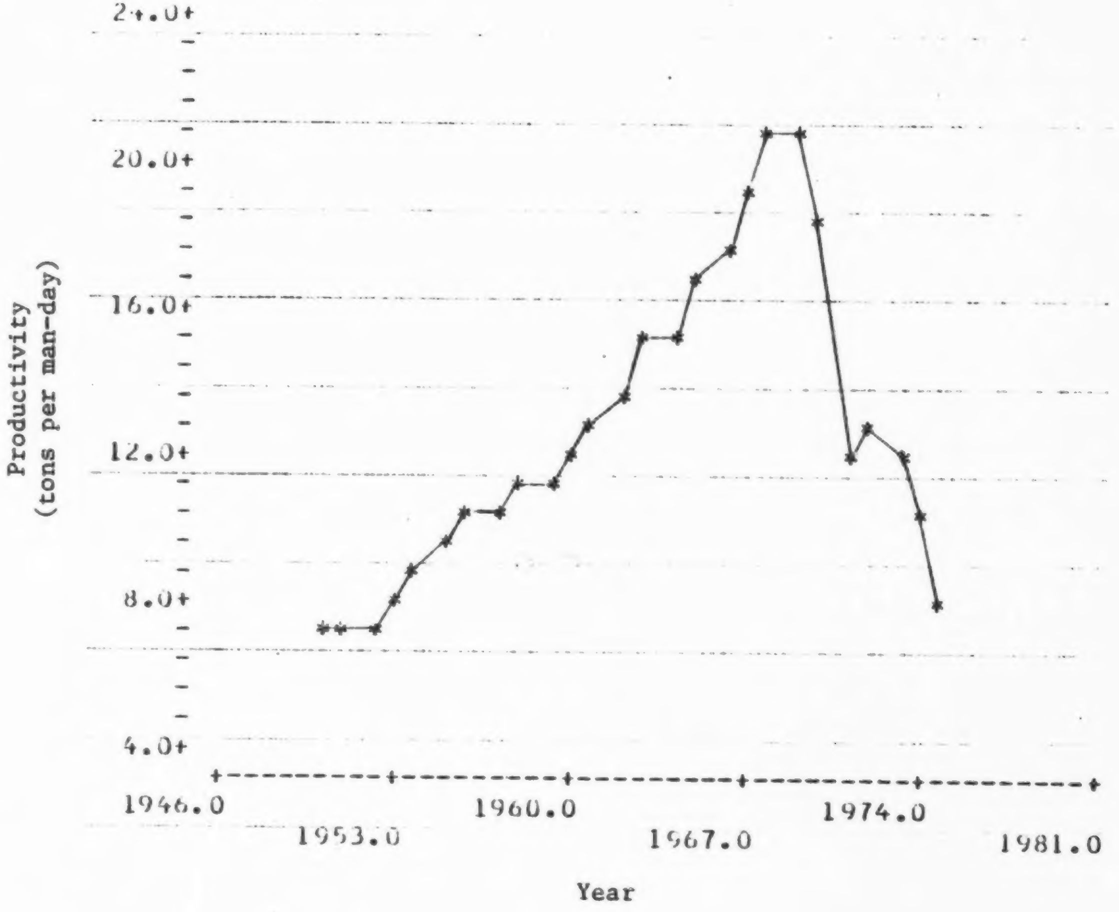


Figure 58. Trend of Productivity in Underground Coal Mines: Ohio (1950 Through 1975)

$R^2 = 0.935$

F-statistic (2,23) = 165.81

Standard error of the regression = 1.1225

****Significant at the 99.0 percent confidence level.

The percent of coal mined by continuous miners (Figure 59) shows a linear increasing trend throughout the 26-year period. Weighted-average seam thickness data (Figure 60) show two distinct populations; from 1950 through 1964, the seam thickness was around 50.0 inches, and from 1965 through 1975, it was around 59.0 inches. This does not appear to be the actual behavior of this variable for the following reason. For the years 1965 through 1975, both the name of the seam being mined and the "average" thickness of the seam for that year was reported for each mine. Therefore, an accurate weighted-average seam thickness could be calculated from 1965 through 1975. For the years 1950 through 1965, each mine reported only the name of the seam being mined. To calculate the approximate weighted-average seam thickness for each year, an "average" thickness for each coal seam was obtained from personnnel at the Ohio Division of Mines (personal communication, 1978). These average values were used as best guesses of the seam thickness at each mine. The values obtained in this way for the years 1950 through 1964 are all lower than those for 1965 through 1975 (Figure 60). A close investigation of the annual mining reports reveals that there was no major change in seams being mined in Ohio or percentages mined from each seam to account for this change. Thus, it seems that those estimates of average values for each underground seam were too low, as compared to values reported in the annual mining reports. It

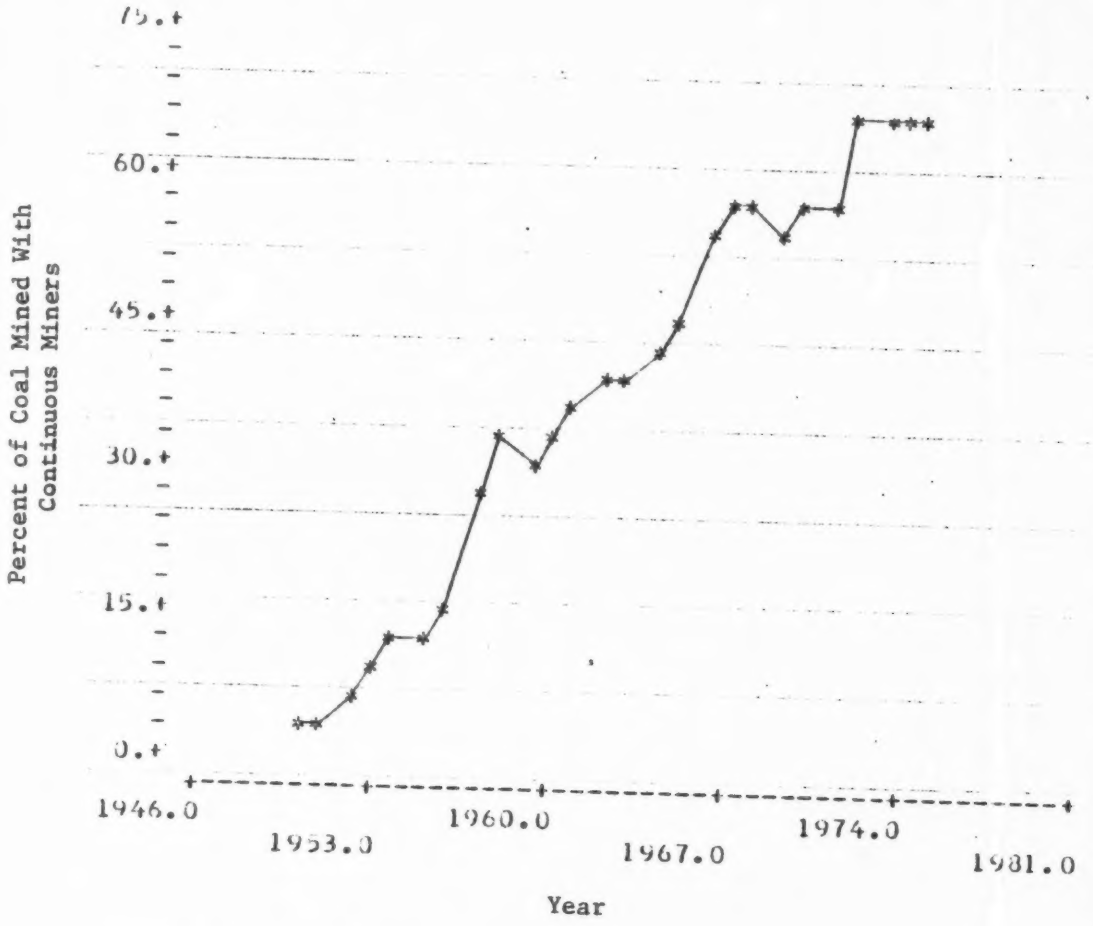


Figure 59. Trend of Percent of Coal Mined With Continuous Miners: Ohio (1950 Through 1975)

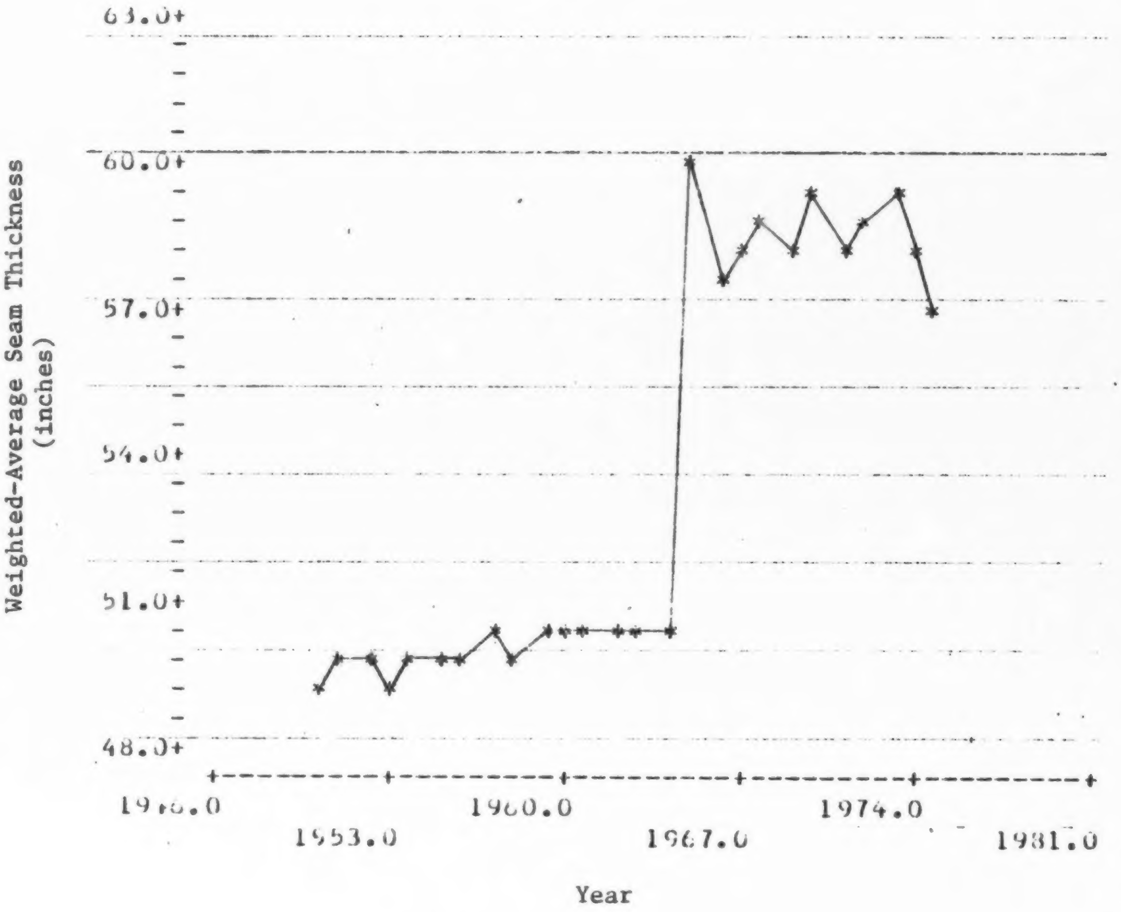


Figure 60. Trend of Weighted-Average Seam Thickness: Ohio (1950 Through 1975)

does seem, however, that looking only at the trend after 1964, seam thickness has an overall level trend. Furthermore, the values before 1965 are also rather constant, although at a lower level. Therefore, it appears to be a safe assumption that seam thickness is essentially a constant in Ohio for the time period under consideration, and it may be omitted from the model. Average production (Figure 61) shows an increasing trend until around 1966, then a larger, positive slope through 1970, finally leveling to a slightly rising or constant trend thereafter. Piecewise regression confirms these breaks in trends at the 99.0 percent confidence level. Weighted-average days in operation (Figure 62) has an increasing trend from 1950 through around 1956; a decreasing trend through 1959; another increasing trend through 1970; then a declining trend through 1975 (98.0 percent confidence level). The actual price of coal in Ohio (Figure 63) was declining through 1968 or 1969, then began to increase, with a large increase in 1974 (99.0 percent confidence level). Assuming there is no Health and Safety Act in 1970 through 1975, estimates indicate that the price of coal would be decreased by approximately 23.14 percent (Fettig, 1978; see Table 25). The resulting price has essentially the same trend as the actual price; however, the increases are not as great (Figure 64).

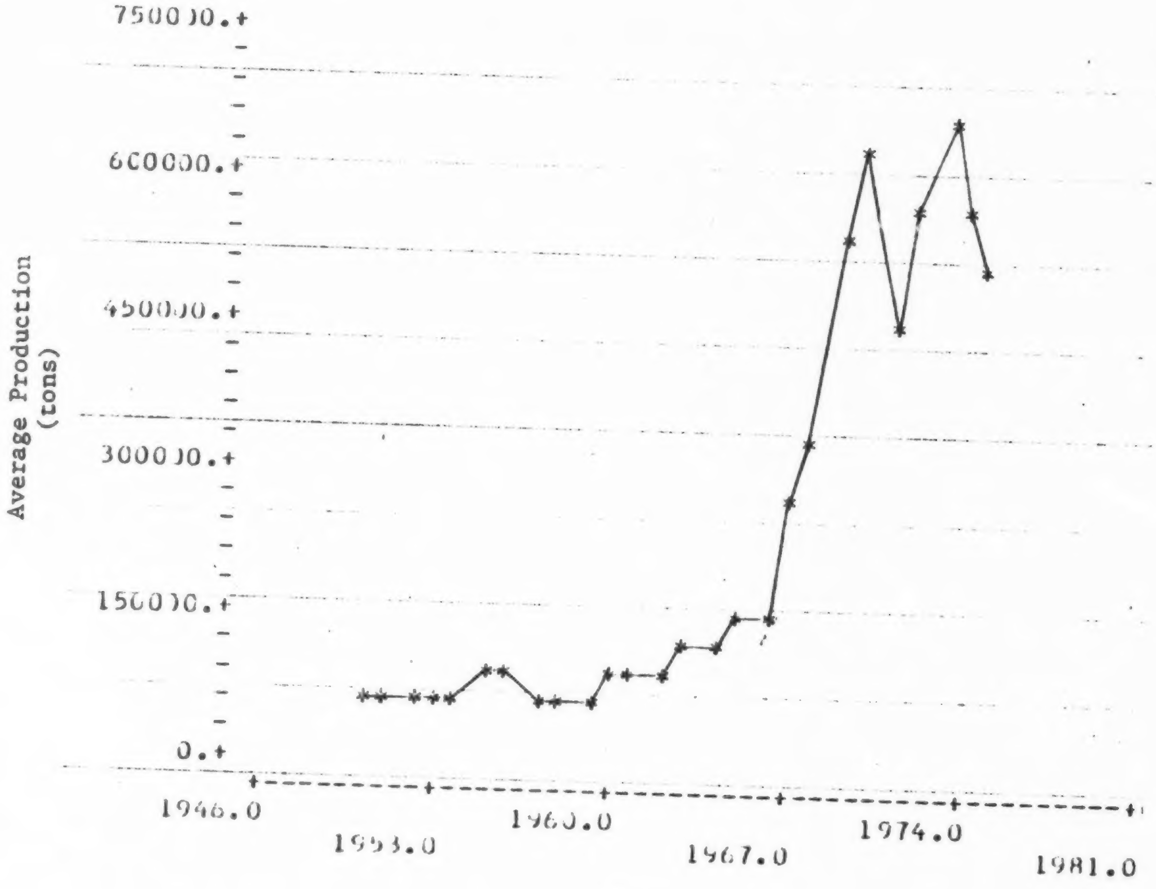


Figure 61. Trend of Average Production: Ohio (1950 Through 1975)

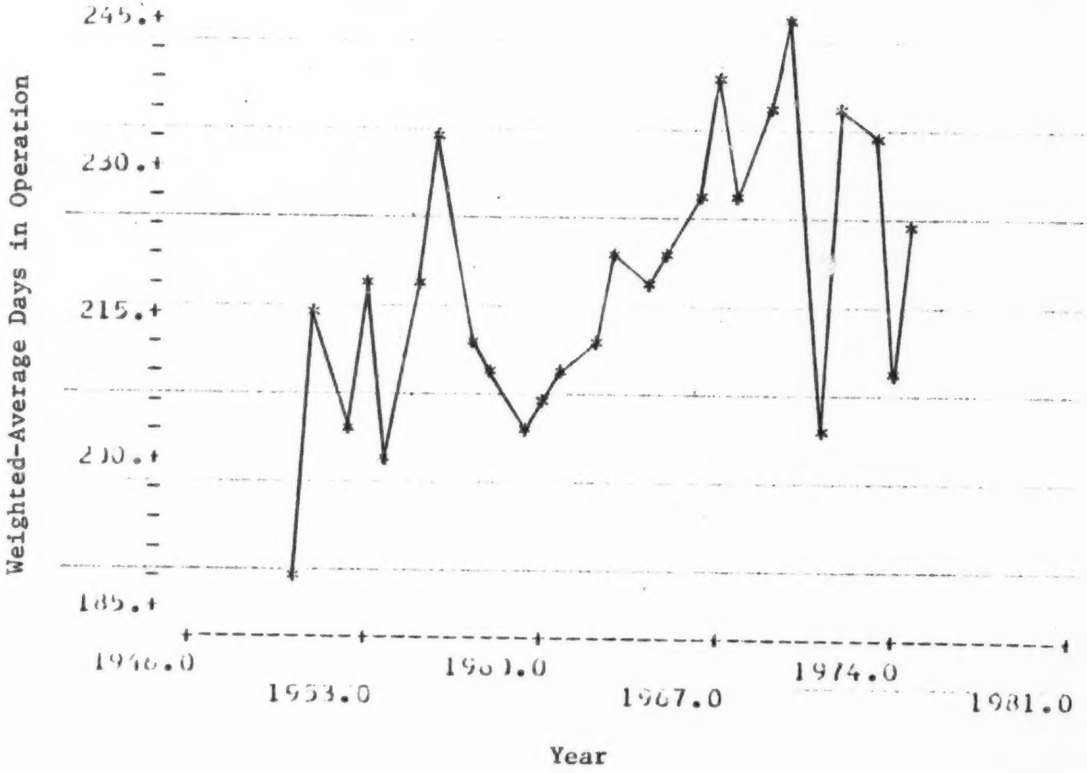


Figure 62. Trend of Weighted-Average Days in Operation: Ohio
(1950 Through 1975)

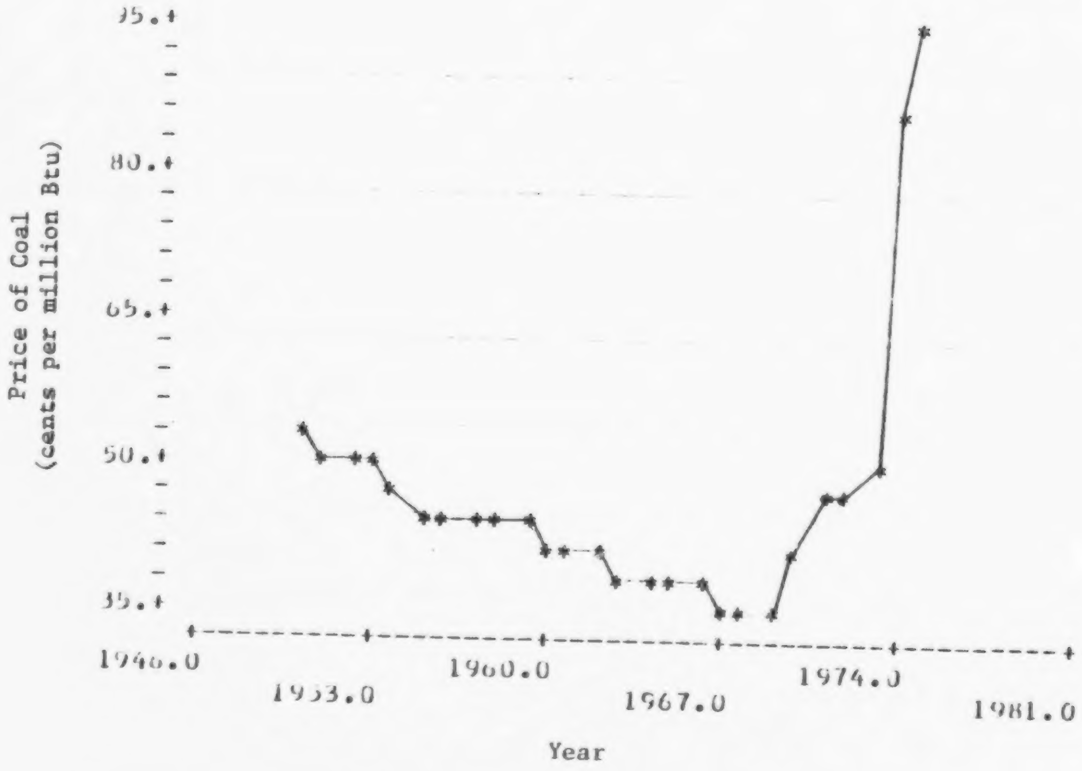


Figure 63. Trend of the Price of Coal: Ohio (1950 Through 1975)

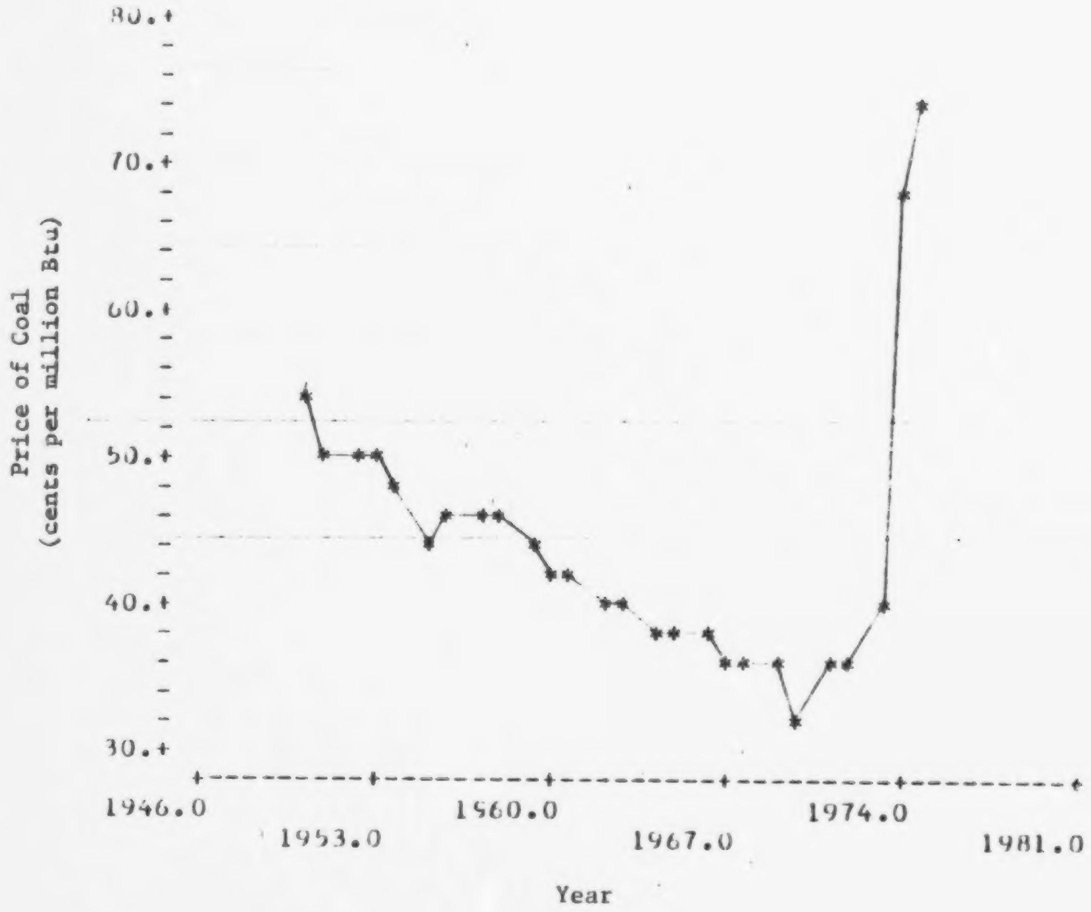


Figure 64. Trend of the Price of Coal Assuming No CMHSA: Ohio (1950 Through 1975)

Results of Regressions for 1950 Through 1975

The results for the OLS regression of the model with seam thickness eliminated for the years 1950 through 1975 are:

$$\begin{aligned} (41)\quad PRY_t &= \underset{(6.97078)}{-5.32470} + \underset{(3.31000)}{1.39698}\, AP_t + \underset{(0.00263686)\#\#\#\#\#}{0.177624}\, CM_t \\ &\quad + \underset{(0.0296894)\#\#}{0.0612383}\, DO_t - \underset{(0.0534086)}{0.0221253}\, PR_t - \underset{(0.0488713)\#\#\#\#}{0.222569}\, MACT_t \end{aligned}$$

$R^2 = 0.9041$

F-statistic (5,20) = 37.7216

Durbin-Watson statistic = 1.5950

Standard error of the regression = 1.46354

Sum of squared residuals = 42.8387.

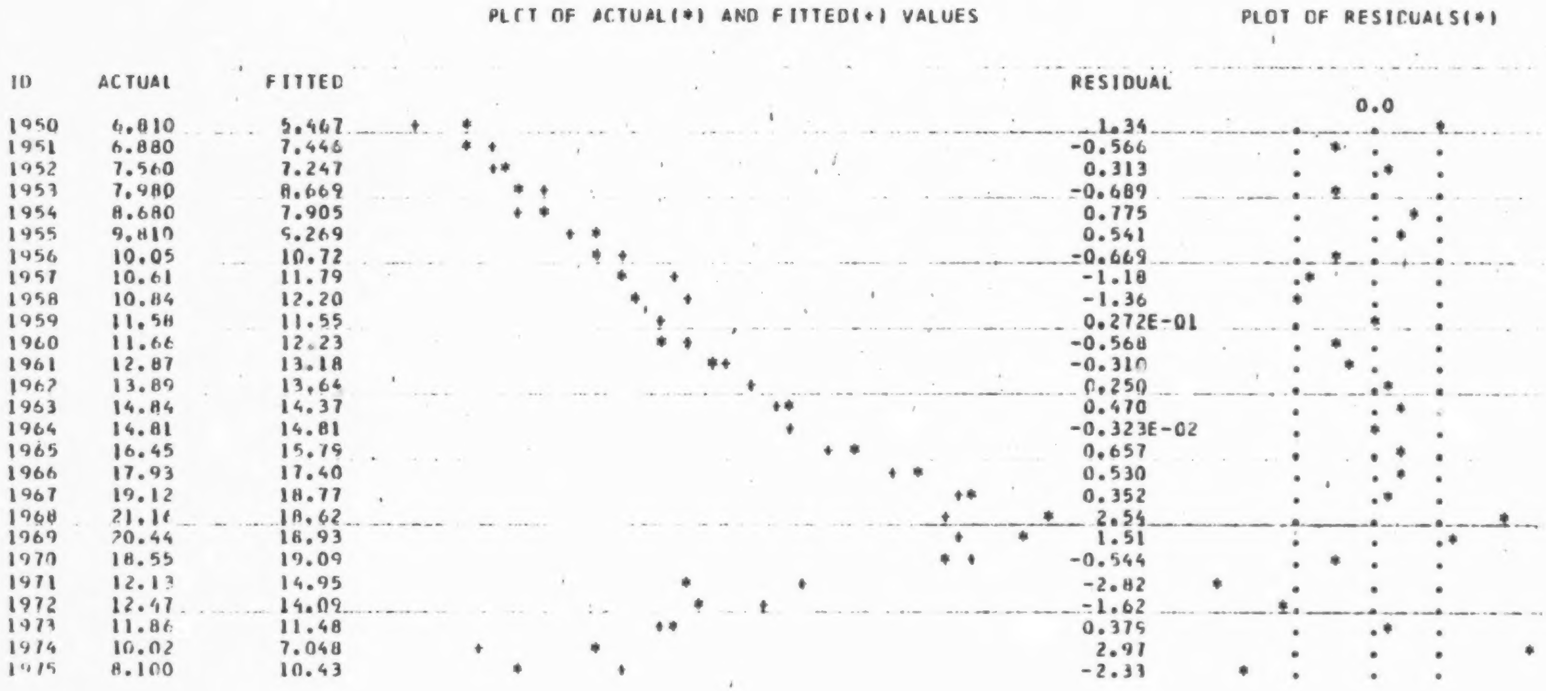
The coefficient of the Mine-Act variable is significant at the 99.0 percent confidence level. The coefficient of CM and DO are significant at the 99.5 and 95.0 percent confidence level, respectively. The coefficients of AP and PR are not significant. All variables have the expected sign. The equation is significant at the 99.0 percent confidence level, and over 90.0 percent of the variation is explained. The Durbin-Watson statistic is in the inconclusive region. However, no autocorrelation is indicated by the Hart-von Neumann test. The greatest pairwise correlation exists between AP and CM (0.82) (Table 26). A plot of actual and fitted values and a plot of the residuals are presented in Figure 65.

The method of principal components was used to correct for multicollinearity. The factor loadings for the principal component and the results of the OLS regression follow.

Table 26

Pairwise Correlation Matrix for AP, CM, DO, PR, and MACT: Ohio (1950 Through 1975)

	AP	CM	DO	PR	MACT
AP	1.0000	0.82315	0.57220	-0.030784	0.74458
CM	0.82315	1.0000	0.56616	-0.19056	0.59612
DO	0.57220	0.56616	1.0000	-0.39291	0.17831
PR	-0.030784	-0.19056	-0.39291	1.0000	0.49516
MACT	0.74458	0.59612	0.17831	0.49516	1.0000



```
ID      ACTUAL     FITTED     RESIDUAL
1950    6.810      5.467       1.34
1951    6.880      7.446      -0.566
1952    7.560      7.247       0.313
1953    7.980      8.669      -0.689
1954    8.680      7.905       0.775
1955    9.810      9.269       0.541
1956    10.05      10.72      -0.669
1957    10.61      11.79      -1.18
1958    10.84      12.20      -1.36
1959    11.58      11.55       0.272E-01
1960    11.66      12.23      -0.568
1961    12.87      13.18      -0.310
1962    13.89      13.64       0.250
1963    14.84      14.37       0.470
1964    14.81      14.81      -0.323E-02
1965    16.45      15.79       0.657
1966    17.93      17.40       0.530
1967    19.12      18.77       0.352
1968    21.16      18.62       2.54
1969    20.44      18.93       1.51
1970    18.55      19.09      -0.544
1971    12.13      14.95      -2.82
1972    12.47      14.09      -1.62
1973    11.86      11.48       0.379
1974    10.02      7.048       2.97
1975    8.100      10.43      -2.33
```

Figure 65. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1975: Ohio (OLS).

Variable	Factor Loadings
AP	0.87544
CM	0.90006
DO	0.82679
PR	-0.37384

$$(42)\ PRY_t = 13.8747 + 4.26229\ PC_t - 0.188167\ MACT_t$$

$$(0.412443)(0.424669)\text{****}\ (0.0278099)\#\#\#\#\#$$

$R^2 = 0.8213$

F-statistic (2,23) = 52.8463

Durbin-Watson statistic = 1.3291

Standard error of the regression = 1.86334

Sum of squared residuals = 79.8568 .

Coefficients of the principal component and the Mine-Act variable are significant at the 99.0 and 99.5 percent confidence levels, respectively. The coefficient of the Mine-Act variable has the expected sign. The F-statistic indicates that the equation is significant at the 99.0 percent confidence level; a lower percentage of the variance is explained using the principal component (82.0) than in Equation 41. The Durbin-Watson statistic is in the inconclusive region. The Hart-von Neumann test indicates positive autocorrelation (95.0 percent confidence level). The degree of multicollinearity is low, as indicated by the correlation matrix below.

	PC	MACT
PC	1.0000	0.47949
MACT	0.47949	1.0000

A plot of actual and fitted values and a plot of the residuals are presented in Figure 66. The residuals plot gives no indication of the presence of heteroskedasticity.

Correcting for both multicollinearity and autocorrelation with both principal components and Cochrane-Orcutt methods yields the following results:

$$(43)\ PRY_t = 13.2747 + 1.68275\ PC_t - 0.0761679\ MACT_t$$
$$(2.52386)(0.577749)^{****}(0.0479916)\#$$

$R^2 = 0.8915$

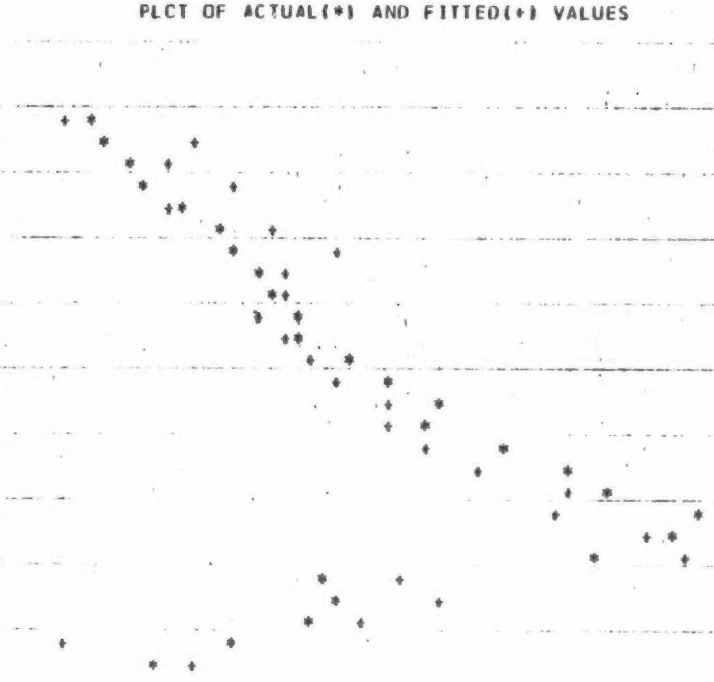
F-statistic (2,22) = 90.4204

Durbin-Watson statistic = 1.3764

Standard error of the regression = 1.42552

Sum of squared residuals = 44.7061.

The coefficients of the principal component and the Mine-Act variable are significant at the 99.0 and 90.0 percent confidence level, respectively. The coefficient of MACT has the expected sign. The equation is significant at the 99.0 percent confidence level; over 89.0 percent of the variation is explained. The Durbin-Watson statistic is in the inconclusive region; however, the Hart-von Neumann test indicates positive autocorrelation (95.0 percent confidence level). A plot of actual and fitted values and a plot of the residuals are presented in Figure 67.



```
ID      ACTUAL      FITTED        RESIDUAL
1950    6.810       6.050         0.760
1951    6.880       9.264        -2.38
1952    7.560       8.411        -0.851
1953    7.980       10.07        -2.09
1954    8.680       8.528         0.152
1955    9.810       10.93        -1.12
1956    10.05       12.65        -2.60
1957    10.61       11.32        -0.709
1958    10.84       11.14        -0.303
1959    11.58       10.67         0.906
1960    11.66       11.25         0.406
1961    12.87       12.04         0.826
1962    13.89       12.45         1.44
1963    14.84       13.73         1.11
1964    14.81       13.77         1.04
1965    16.45       14.74         1.71
1966    17.93       15.91         2.02
1967    19.12       18.14         0.977
1968    21.16       17.73         3.43
1969    20.44       19.85         0.589
1970    18.55       20.98        -2.43
1971    12.13       13.97        -1.84
1972    12.47       15.13        -2.66
1973    11.86       13.05        -1.19
1974    10.02       6.165         3.86
1975    8.100       9.133        -1.03
```

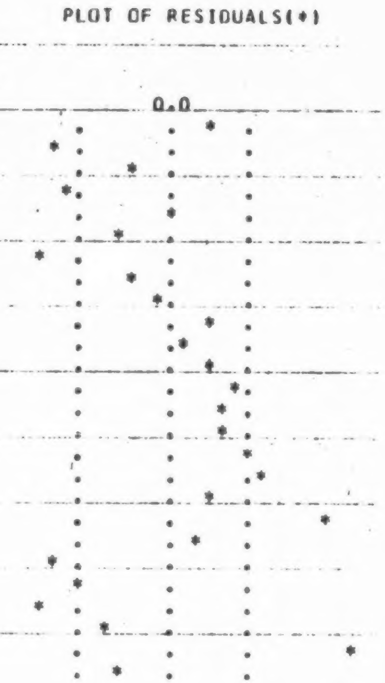
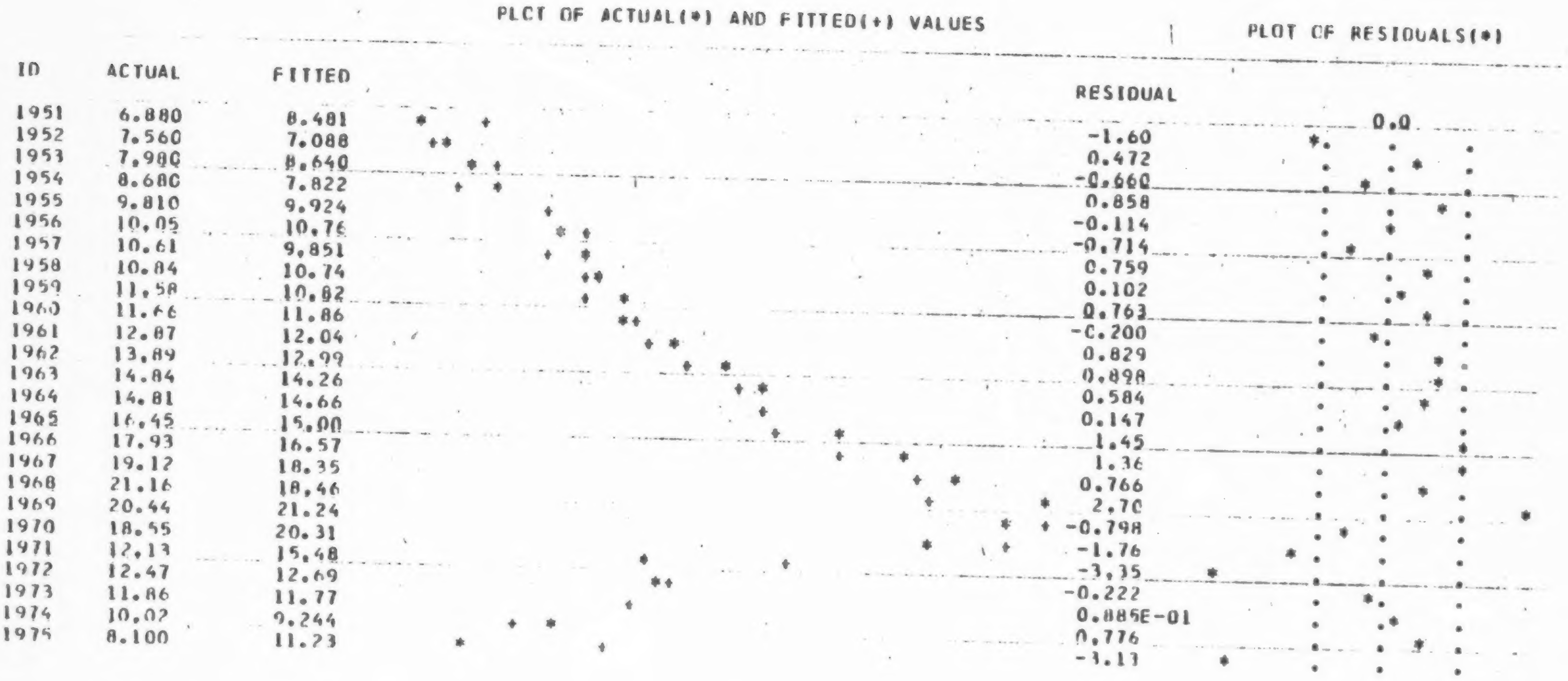


Figure 66 Plots for Productivity Model Excluding Seam Thickness Using Principal Components, 1950 Through 1975: Ohio (OLS).



ID	ACTUAL	FITTED	RESIDUAL
1951	6.880	8.481	-1.60
1952	7.560	7.088	0.472
1953	7.980	8.640	-0.660
1954	8.680	7.822	0.858
1955	9.810	9.924	-0.114
1956	10.05	10.76	-0.714
1957	10.61	9.851	0.759
1958	10.84	10.74	0.102
1959	11.58	10.82	0.763
1960	11.66	11.86	-0.200
1961	12.87	12.04	0.829
1962	13.89	12.99	0.898
1963	14.84	14.26	0.584
1964	14.81	14.66	0.147
1965	16.45	15.00	1.45
1966	17.93	16.57	1.36
1967	19.12	18.35	0.766
1968	21.16	18.46	2.70
1969	20.44	21.24	-0.798
1970	18.55	20.31	-1.76
1971	12.13	15.48	-3.35
1972	12.47	12.69	-0.222
1973	11.86	11.77	0.885E-01
1974	10.02	9.244	0.776
1975	8.100	11.23	-3.13

Figure 67. Plots for Productivity Model Excluding Seam Thickness Using Principal Components, 1950 Through 1975: Ohio (CORC).

F

Results of Regressions for 1950 Through 1969 and Predictions of Productivity

This section derives predictions of productivity levels that might have been achieved in 1970 through 1975 if the 1969 Coal Mine Health and Safety Act had not been passed. First, a time trend of productivity from 1950 through 1969 is used to predict possible levels of productivity; second, estimates of the multivariate model were made using values of the independent variables for 1950 through 1969. Productivity levels are predicted for 1970 through 1975 using values of the independent variables in these years. Third, predictions are made based on the results of the model for 1950 through 1975 by subtracting the negative influence of MACT on productivity. Predicted levels are compared with actual levels.

To investigate whether the legislation appears to have had indirect effects on productivity by affecting the other independent variables, the trend of each is reexamined for any changes in trend in 1969. In Figure 59, the percent of coal mined by continuous miners shows an overall increasing trend. Weighted-average days in operation (Figure 60) increases through 1956, decreases through 1959, increases through 1970, then levels or decreases somewhat after 1970. Piecewise regression indicates that a break in trend in 1969 is also significant (99.0 percent confidence level). This would be more likely to be due to an increase in wildcat strikes or perhaps reaching the "natural" limit than to the Mine Act. Average production (Figure 61) shows a change in trend in 1969 at the 99.0 percent confidence level. It is unlikely that this change from a rising trend from 1966 through 1970 to a more level trend could be due to the Mine Act, since the most likely effect of the Act would be the closure of smaller mines, as explained in the section on West Virginia. Thus, the expected effect would be to increase average production (mine size), rather than to decrease it. The actual cost of coal was certainly affected by the Mine Act; however, this effect has been accounted for by subtracting out the estimated portion of the actual cost rise that was due to the existence of the Mine Act in 1970 through 1975. Thus, it seems unlikely that the Mine Act has had large, if any, effects on the other independent variables.

Productivity shows a positive trend with time through 1969; after 1969 the trend becomes negative. A simple regression of productivity with time (T) from 1 (1950) through 20 (1969) was run. The results are:

$$(44)\ PRY_t = \underset{(0.414162)}{4.87443} + \underset{(0.0345736)^{****}}{0.745149}\,T$$

$R^2 = 0.9627$

F-statistic (1,18) = 464.511

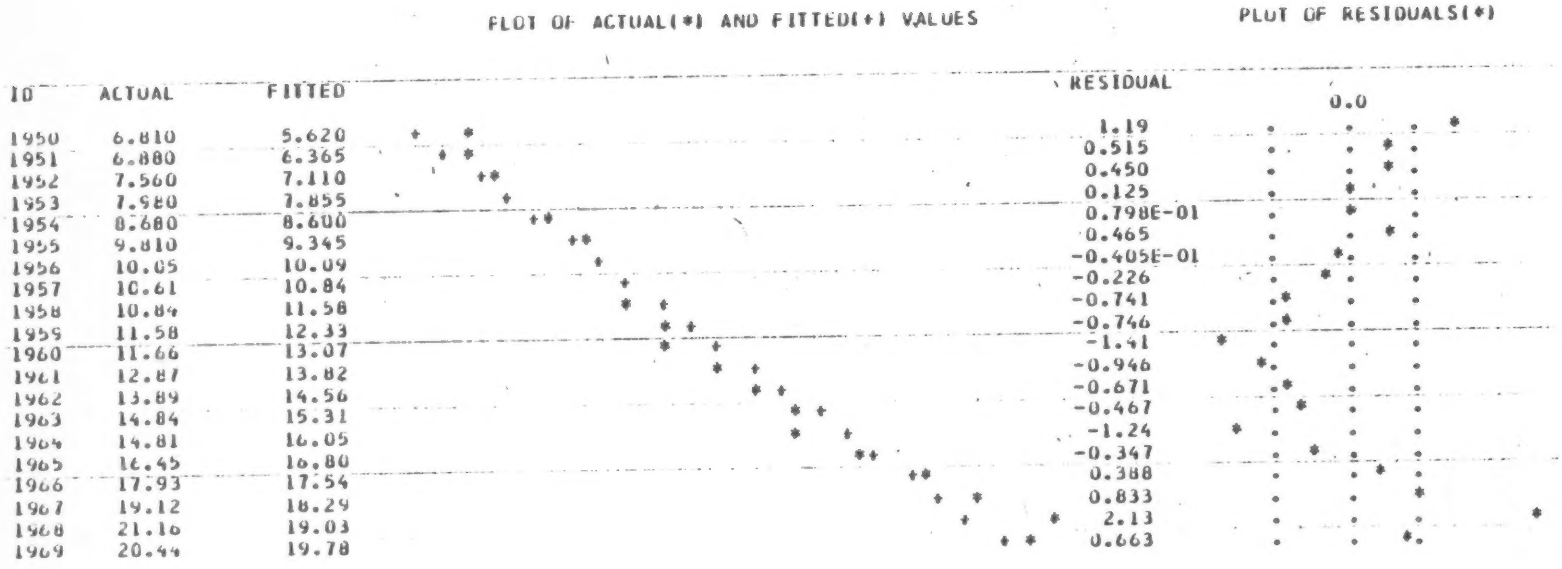
Durbin-Watson statistic = 0.5598

Standard error of the regression = 0.891571

Sum of squared residuals = 14.3082.

This regression results in strong positive autocorrelation (99.0 percent confidence level). The residuals plot (Figure 68) shows a distinct "u"-shape due to attempting to fit the somewhat curved trend with a straight line. The Cochrane-Orcutt technique is very successful in this case, as the following results show.

$$(45)\ PRY_t = \underset{(1.12537)}{3.55325} + \underset{(0.0789529)^{****}}{0.836228}\,T$$



```
                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES                 PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                                RESIDUAL          0.0
1950    6.810       5.620                                                 1.19
1951    6.880       6.365                                                 0.515
1952    7.560       7.110                                                 0.450
1953    7.980       7.855                                                 0.125
1954    8.680       8.600                                                 0.798E-01
1955    9.810       9.345                                                 0.465
1956    10.05       10.09                                                 -0.405E-01
1957    10.61       10.84                                                 -0.226
1958    10.84       11.58                                                 -0.741
1959    11.58       12.33                                                 -0.746
1960    11.66       13.07                                                 -1.41
1961    12.87       13.82                                                 -0.946
1962    13.89       14.56                                                 -0.671
1963    14.84       15.31                                                 -0.467
1964    14.81       16.05                                                 -1.24
1965    16.45       16.80                                                 -0.347
1966    17.93       17.54                                                 0.388
1967    19.12       18.29                                                 0.833
1968    21.16       19.03                                                 2.13
1969    20.44       19.78                                                 0.663
```

Figure 68. Plots for Time Trend of Productivity, 1950 Through 1969: Ohio (OLS).

$R^2 = 0.9826$

F-statistic (1,17) = 957.884

Durbin-Watson statistic = 1.9952

Standard error of the regression = 0.596648

Sum of squared residuals = 6.05181 .

There is no autocorrelation (Durbin-Watson statistic = 1.995), and R^2 is over 98.0 percent. The equation is significant at the 99.0 percent confidence level. Residuals and actual and fitted values are shown in Figure 69.

Values of productivity that were predicted using Equation 45 are shown in Table 27. The predictions are for increasing productivities through time that are significantly higher than actual values.

Similarly, a regression was run for 1950 through 1969 with productivity as a function of average production, percent mined by continuous miners, weighted-average days in operation, and price. The results are:

$$
\begin{array}{llll}
(46)\ PRY_t = & 16.3525 & + 9.48200\ AP_t & + 0.115331\ CM_t \\
 & (8.46883) & (2.10793)\#\#\#\#\# & (0.0324832)\#\#\#\#\# \\
 & + 0.0106277\ DO_t & - 0.248338\ PR_t & \\
 & (0.0199114) & (0.112414)\#\#\# &
\end{array}
$$

$R^2 = 0.9814$

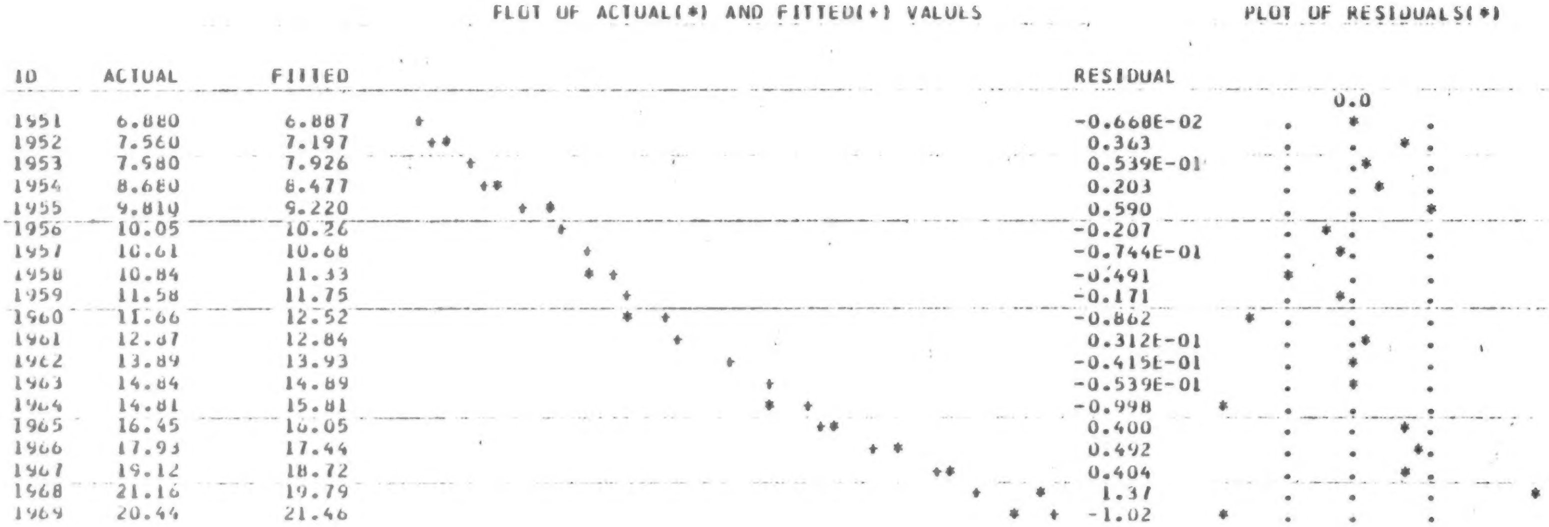
F-statistic (4,15) = 198.188

Durbin-Watson statistic = 1.5719

Standard error of the regression = 0.689081

Sum of squared residuals = 7.12249 .

Coefficients of AP, CM, and PR are significant at the 99.5, 99.5, and 97.5 percent confidence level, respectively, even though there is



```
                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES        PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                  RESIDUAL
                                                                                  0.0
1951     6.880       6.887                                  -0.668E-02
1952     7.560       7.197                                   0.363
1953     7.980       7.926                                   0.539E-01
1954     8.680       8.477                                   0.203
1955     9.810       9.220                                   0.590
1956    10.05       10.26                                   -0.207
1957    10.61       10.68                                   -0.744E-01
1958    10.84       11.33                                   -0.491
1959    11.58       11.75                                   -0.171
1960    11.66       12.52                                   -0.862
1961    12.87       12.84                                    0.312E-01
1962    13.89       13.93                                   -0.415E-01
1963    14.84       14.89                                   -0.539E-01
1964    14.81       15.81                                   -0.998
1965    16.45       16.05                                    0.400
1966    17.93       17.44                                    0.492
1967    19.12       18.72                                    0.404
1968    21.16       19.79                                    1.37
1969    20.44       21.46                                   -1.02
```

Figure 69. Plots for Time Trend of Productivity, 1950 Through 1969: Ohio (CORC).

Table 27

Comparison of Predicted Levels of Productivity Based on a Time Trend and on Multiple Regressions With Actual Levels of Productivity for Ohio

	Productivity (tons per man-day)		
Year	Actual	Based on Simple Time Trend (CORC)	Based on AP, CM, DO, and PR (OLS)
1970	18.55	21.11 (±1.53)	23.94 (±2.35)
1971	12.13	21.95 (±1.56)	20.70 (±2.28)
1972	12.47	22.79 (±1.62)	22.67 (±2.19)
1973	11.86	23.62 (±1.66)	23.20 (±2.71)
1974	10.02	24.46 (±1.70)	15.04 (±7.96)
1975	8.10	25.29 (±1.74)	12.95 (±9.55)

Note: Prediction intervals for a 95.0 percent confidence level are given in parentheses.

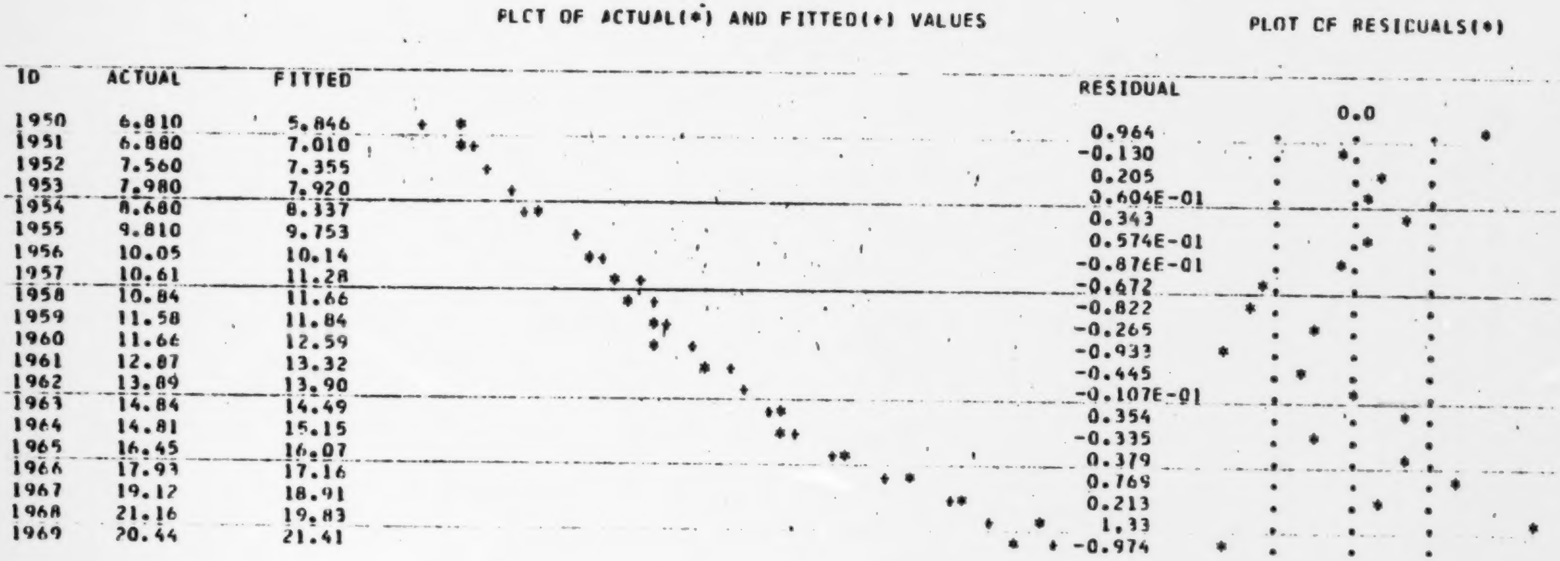
significant correlation between PR and CM (-0.96) (Table 28). The coefficient of DO is not significant. All coefficients have the expected signs. The equation is significant at the 99.0 percent confidence level, and over 98.0 percent of the variation is explained. The Durbin-Watson statistic is in the inconclusive region. However, the Hart-von Neumann test indicates no autocorrelation. Appropriate plots are shown in Figure 70. There is no evidence for the presence of heteroskedasticity. Predictions based on Equation 46 are given in Table 27. In contrast to the time trend model, these predictions indicate declining productivities over time that are significantly greater than actual values in 1970 through 1973. In 1974 and 1975, actual values are within the wide prediction intervals.

Using the results of the model for 1950 through 1975, predictions of productivity without the Mine Act were made by adding the amount of productivity lost due to the Mine Act to the prediction of productivity. These predictions, shown in Table 29, are for productivities that are greater than actual values in all years. In 1975, the predicted value is 19.16 as compared to an actual value of 8.10 tons per man-day. The effect of price (PR) on productivity is also shown in Table 29; this effect is smaller than that of the Mine Act in all years. Percentage losses in productivity due to MACT are shown in Table 30. The results indicate that productivity was down by around 45.6 percent in 1975 due to the Mine Act.

Table 28

Pairwise Correlation Matrix for AP, CM, DO, and PR: Ohio (1950 Through 1969)

	AP	CM	DO	PR
AP	1.0000	0.69858	0.69072	-0.67526
CM	0.69858	1.0000	0.62357	-0.95793
DO	0.69072	0.62357	1.0000	-0.69293
PR	-0.67526	-0.95793	-0.69293	1.0000



```
                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)
ID     ACTUAL     FITTED                                  RESIDUAL
                                                                          0.0
1950   6.810      5.846                                   0.964
1951   6.880      7.010                                  -0.130
1952   7.560      7.355                                   0.205
1953   7.980      7.920                                   0.604E-01
1954   8.680      8.337                                   0.343
1955   9.810      9.753                                   0.574E-01
1956   10.05      10.14                                  -0.876E-01
1957   10.61      11.28                                  -0.672
1958   10.84      11.66                                  -0.822
1959   11.58      11.84                                  -0.265
1960   11.66      12.59                                  -0.933
1961   12.87      13.32                                  -0.445
1962   13.89      13.90                                  -0.107E-01
1963   14.84      14.49                                   0.354
1964   14.81      15.15                                  -0.335
1965   16.45      16.07                                   0.379
1966   17.93      17.16                                   0.769
1967   19.12      18.91                                   0.213
1968   21.16      19.83                                   1.33
1969   20.44      21.41                                  -0.974
```

Figure 70. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1969: Ohio (OLS).

Table 29

Effect of MACT and PR on Productivity: Ohio*

Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT	Mean		(2) Value of MACT	Tons Per Man-Day (3) Reduction in Productivity Caused by MACT Low	Mean	High -((1) x (2))	(4) Prediction of Productivity from Model (95.0 percent confidence level)	(5) Prediction of Productivity Without MACT Low	Mean	High (4) + (3)	(6) Actual Productivity
1969	-0.325	-0.223	-0.121	0				18.93				20.44
1970				5.15924	0.62	1.15	1.68	19.09	19.71	20.24	20.77	18.55
1971				10.4678	1.27	2.33	3.40	14.95	16.22	17.28	18.35	12.13
1972				29.2330	3.54	6.52	9.50	14.09	17.63	20.61	23.59	12.47
1973				42.6833	5.16	9.52	13.87	11.48	16.64	21.00	25.35	11.86
1974				52.0947	6.30	11.62	16.93	7.05	13.35	18.67	23.98	10.02
1975				39.1479	4.74	8.73	12.72	10.43	15.17	19.16	23.15	8.10

Year	(7) 95.0 Percent Confidence Interval for Coefficient of PR	Mean		Cents Per Million Btu (8) Value of PR	(9) Change in PR From 1969	Tons Per Man-Day (10) Reduction in Productivity Caused by Change in PR Low	Mean	High -((7) x (9))
1969	-0.134	-0.022	0.089	35.6				
1970				31.1	-4.5	0.40	-0.10	-0.60
1971				35.5	-0.1	0.01	-0.00	-0.01
1972				37.0	1.4	-0.12	0.03	0.19
1973				39.4	3.8	-0.34	0.08	0.51
1974				67.1	31.5	-2.80	0.78	4.22
1975				73.2	37.6	-3.35	0.83	5.04

[*] Using results of Equation 41.

Table 30

Percentage Losses in Productivity Due to the Mine Act in Ohio

Year	Using Predictions of Regression 41 (data through 1975) (percentage loss)
1970	5.7
1971	13.5
1972	31.6
1973	45.3
1974	62.2
1975	45.6
Average Per Year	34.0

Summary

Some of the results of the regressions are presented in Tables 31 and 32. The relationships of the independent variables to productivity in the model using data for 1950 through 1975 may be summarized as follows: (1) average production is positively related and not significant; (2) percent mined by continuous miners is positively related and highly significant; (3) weighted-average days in operation is positively related and significant; (4) price is negatively related and not significant; and (5) the Mine-Act variable is negatively related and significant. The regression analyses indicate that the effects of each independent variable on productivity in terms of approximate magnitude are: (1) an increase in average production of 0.1 million tons increases productivity by 0.1 tons per man-day; (2) an increase in percent mined by continuous miners of 1.0 increases productivity by 0.2 tons per man-day; (3) an increase of 10.0 in weighted-average days in operation increases productivity by 0.1 tons per man-day; (4) an increase in price of 1.0 cent per million Btu decreases productivity by 0.02 tons per man-day; and (5) an increase of severity of Act implementation as approximated by a rise of 10.0 in inspection per mine decreases productivity by 0.2 tons per man-day.

The results of these regressions for Ohio indicate that the Mine Act was responsible for losses in productivity in 1970 through 1975 of approximately 6, 14, 32, 45, 62, and 46 percent, respectively.

Table 31

Results of Regressions Summary for Ohio

Equation	Constant	AP	CM	DO	PR	MACT	PC	T(Year)	R^2	S	SSR	Autocorrelation (Durbin-Watson Statistic)	F-Statistic
								1950 Through 1975					
41(OLS)	-5.325	1.397	0.178 #####	0.061 ##	-0.022	-0.223 ####			0.90	1.46	42.84	None (1.60)	$37.72_{(5,20)}$
42(OLS)	13.875					-0.188 #####	4.262 ****		0.82	1.86	79.86	+(1.33)	$52.85_{(2,23)}$
43(CORC)	13.275					-0.076 #	1.683 ****		0.89	1.43	44.71	+(1.38)	$90.42_{(2,22)}$
								1950 Through 1969					
44(OLS)	4.874							0.745 ****	0.96	0.89	14.31	+(0.56)	$464.51_{(1,18)}$
45(CORC)	3.553							0.836 ****	0.98	0.60	6.05	None (2.00)	$957.88_{(1,17)}$
46(OLS)	16.353	9.482 #####	0.115 #####	0.011	-0.248 ###				0.98	0.69	7.12	None (1.57)	$198.19_{(4,15)}$

Significance Levels:
**** Significant at 99.0 percent confidence level (two-tail test)
# Significant at 90.0 percent confidence level (one-tail test)
Significant at 95.0 percent confidence level (one-tail test)
Significant at 97.5 percent confidence level (one-tail test)
Significant at 99.0 percent confidence level (one-tail test)
Significant at 99.5 percent confidence level (one-tail test)

Table 32

Ninety-Five Percent Confidence Intervals for Coefficients in Ohio Regression

Equation	AP		CM		DO		PR		MACT		PC		T	
							1950 Through 1975							
41(OLS)	-5.51	8.30	0.17	0.18	0.00	0.12	-0.13	0.09	-0.33	-0.12				
42(OLS)									-0.25	-0.13	3.38	5.14		
43(CORC)									-0.18	0.02	0.48	2.88		
							1950 Through 1969							
44(OLS)													0.67	0.82
45(CORC)													0.67	1.00
46(OLS)	4.99	13.98	0.05	0.18	-0.03	0.05	-0.49	-0.01						

Eastern Kentucky

Data and Trends of Variables

The data used for eastern Kentucky are presented in Table 33. The state data on productivity (derived from figures on total production, employment, and days in operation), days in operation, and average production were obtained from the Kentucky Department of Mines and Minerals Annual Report for 1950 through 1959 and 1964 through 1975. Seam thickness data are available only in 1950 through 1959; in the other years, the name of the seam is given at the mine level. For these other years, data were obtained as in Ohio, that is, from personnel in the state's Department of Mines and Minerals. Data are available for all these years for rail-connected mines only. Complete mine level data for truck mines are available only from 1964 through 1975. Data in 1960 and 1963 are incomplete since many mines' statistics were held confidential. In 1961 and 1962, no mine level data are reported. Other data sources are as reported in the section on Methods of Investigation. Results are presented for regressions using data for rail-connected mines. Estimated data for the years 1960 through 1963 (Table 34) were derived and used for the regressions. These results are presented along with the results obtained with no observations in 1960 through 1963. Corresponding equations using estimated data are designated with an "E" following the number. Results for all mines (truck and rail) are given in summary form.

The trend of productivity in eastern Kentucky is shown in Figure 71. There was a steady increase from 1950 (4.89 tons per man-day) through 1968 (15.86 tons per man-day); productivity dropped slightly in 1969

Table 33

Data for Eastern Kentucky, Underground Rail-Connected Mines

Year	Productivity PRY (tons per man-day)	Average Production AP^a (tons)	Weighted-Average Seam Thickness ST (inches)	Weighted-Average Seam Thickness Adjusted ST (inches)	Percent of Coal Mined by Continuous Miners CM (percent)	Weighted-Average Days in Operation DO	Actual Price of Coal, 1975 Dollars PR_A (cents per million Btu)	Price of Coal Under the Assumption of No-Act, 1975 Dollars PR (cents per million Btu)	Number of Inspections Per Mine Under CMHSA MACT
1950	4.89	169423	47.23	47.23	0.17	183	49.6	49.6	0.0
1951	5.23	193834	47.53	47.53	0.30	204	45.3	45.3	0.0
1952	5.75	156744	47.46	47.46	0.52	188	44.7	44.7	0.0
1953	6.45	158462	49.06	49.06	0.90	197	43.4	43.4	0.0
1954	7.36	146801	49.55	49.55	1.19	202	39.8	39.8	0.0
1955	7.57	158790	50.61	50.61	1.79	213	37.5	37.5	0.0
1956	7.93	176539	49.39	49.39	2.22	211	36.2	36.2	0.0
1957	8.86	171451	50.13	50.13	4.18	219	36.0	36.0	0.0
1958	9.64	174721	49.74	49.74	6.95	208	34.8	34.8	0.0
1959	10.60	192789	50.24	50.24	7.19	194	33.2	33.2	0.0
1964	12.73	216607	44.73	50.73	12.55	224	28.7	28.7	0.0
1965	12.99	253211	43.98	49.98	14.02	229	27.7	27.7	0.0
1966	13.74	269440	45.40	51.40	12.16	228	27.0	27.0	0.0
1967	15.52	320562	44.74	50.74	15.71	228	27.7	27.7	0.0
1968	15.86	281915	45.10	51.10	17.37	230	27.0	27.0	0.0
1969	15.25	283749	45.36	51.36	19.15	235	27.1	27.1	0.0
1970	13.49	245910	45.33	51.33	17.88	233	30.8	24.1	5.15924
1971	11.21	213255	44.88	50.88	20.81	219	33.5	26.2	10.4678
1972	11.74	206103	45.62	51.62	22.62	230	35.4	27.7	29.2330
1973	11.65	242099	45.56	51.56	21.99	238	37.1	29.0	42.6833
1974	10.02	215198	46.23	52.23	30.92	225	54.4	42.6	52.0947
1975	9.70	211295	45.45	51.45	31.85	227	64.2	50.3	39.1497

Table 34

Estimated Data for Eastern Kentucky: Underground Rail-Connected Mines (1960 through 1963)[*]

	PRY (tons per man-day)	AP (tons)	ST (inches)	DO (days)
1959 (actual values)	10.60	192789	50.24	194
1960	11.03	197553	50.34	200
1961	11.45	202316	50.44	206
1962	11.88	207080	50.53	212
1963	12.30	211843	50.63	218
1964 (actual values except ST)	12.73	216607	50.73	224

[*] Estimates are based on straight line between 1959 and 1964.

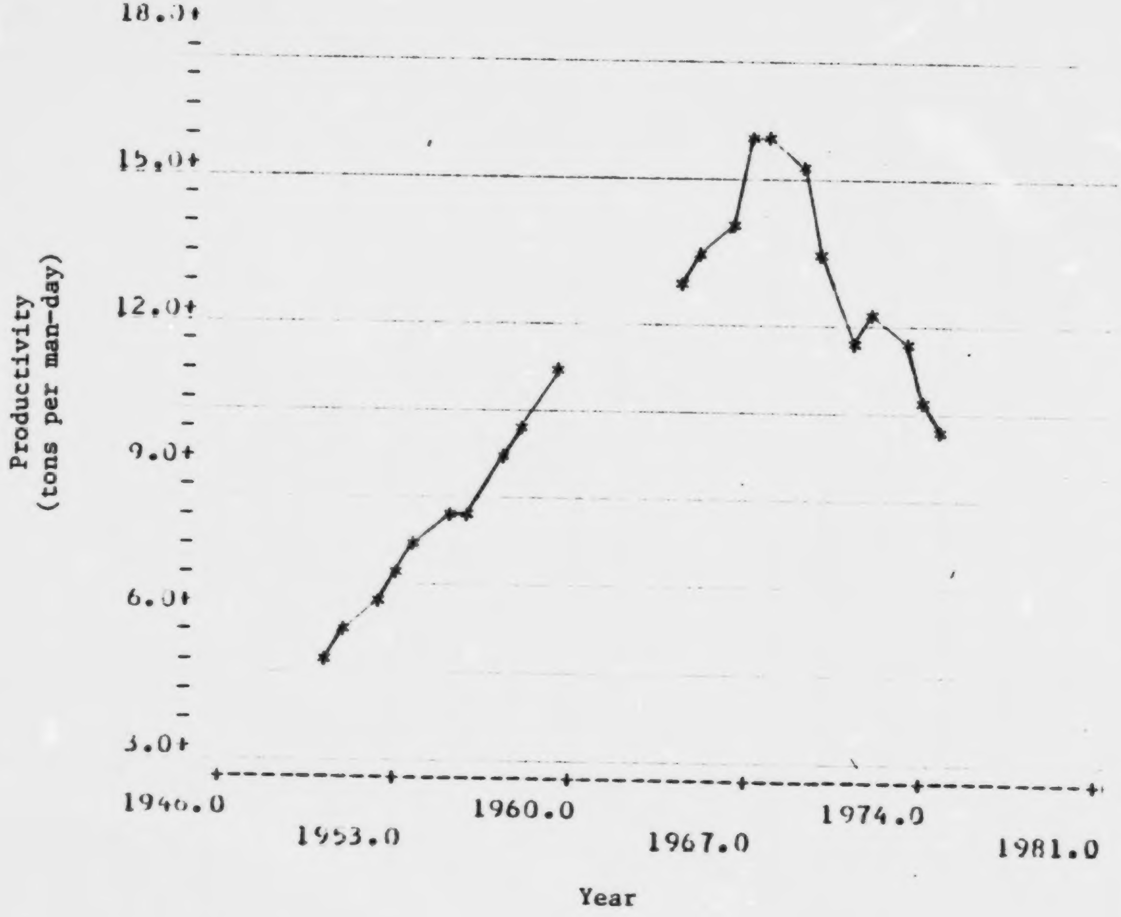


Figure 71. Trend of Productivity in Underground Rail-Connected Coal Mines: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

(15.25 tons per man-day), then declined through 1975. In the years 1950 through 1955, productivity increased by 54.8 percent overall; in 1955 through 1959, the increase was 40.0 percent; from 1959 through 1965, the increase was 22.5 percent; in 1965 through 1969, the overall percentage increase was 17.4 percent. The overall decline in productivity from 1969 through 1975 was 36.4 percent; in 1975, the level had dropped to 9.70 tons per man-day, similar to levels attained in 1958 through 1959.

Using piecewise regression, it was found that the change in the trend of productivity with time since the 1969 Coal Mine Health and Safety Act took effect is statistically significant at the 99.0 percent confidence level. The results for this regression using a join point of 20 (1969) are:

$$\text{(47)}\quad PRY_t = \underset{(0.323)}{4.376} + \underset{(0.0258)^{****}}{0.5514}\, X_1 - \underset{(0.117)^{****}}{1.622}\, X_2\,(X_1 - 20)$$

$R^2 = 0.96$

F-statistic (2,19) = 230.10

Standard error of the regression = 0.704

****Significant at the 99.0 percent confidence level.

Since productivity actually reached a peak in 1968, a piecewise regression was made using join points of 19 (1968) and 20 (1969). The results are:

$$\text{(47A)}\quad PRY_t = \underset{(0.266)}{4.103} + \underset{(0.0241)^{****}}{0.5970}\, X_1 - \underset{(0.479)^{****}}{1.696}\, X_2\,(X_1 - 19)$$

$$+ \underset{(0.543)}{0.273}\, X_3\,(X_1 - 20)$$

$R^2 = 0.977$

F-statistic (3,18) = 250.40

Standard error of the regression = 0.555

****Significant at the 99.0 percent confidence level.

The join point in 1968 is the statistically significant one (99.0 percent confidence level).

The percent of coal mined by continuous miners (Figure 72) shows an increasing trend throughout the time period. Weighted-average seam thickness (Figure 73) data show two distinct populations, from 1950 through 1959 and from 1964 through 1975. The latter group of data points all have smaller seam thicknesses. As in the case of Ohio, this appears to be due to using for 1964 to 1975 approximate average seam thickness values obtained from personnel in the Department of Mines and Minerals. Since there is no reason to expect the average seam thickness to be discontinuous in this way, it is thought that the actual behavior of the seam thickness variable has not been measured accurately. Weighted-average seam thickness has an upward trend both from 1950 through 1959 and from 1964 through 1975. The second set of data has a less reliable basis and thus is more likely to be the less reliable set of figures. The best approximation that can be made of the actual behavior of the variables is to add a constant value to all values in 1964 through 1975 such that these data points remain in trend with immediately preceding ones. The amount added to each is six inches. The resulting adjusted values are shown in Table 33 and are plotted in Figure 74. The analysis is presented both with and without seam thickness in the model. Weighted-average days in operation (Figure 75)

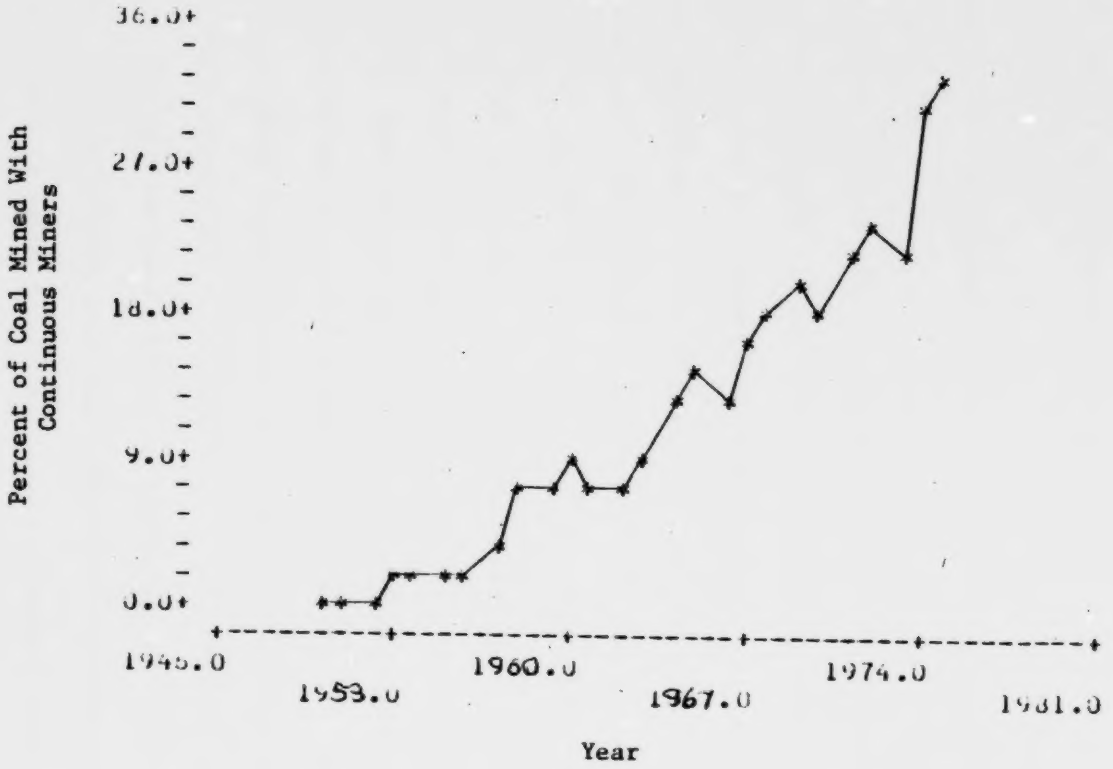


Figure 72 . Trend of Percent of Coal Mined With Continuous Miners: Eastern Kentucky (1950 Through 1975)

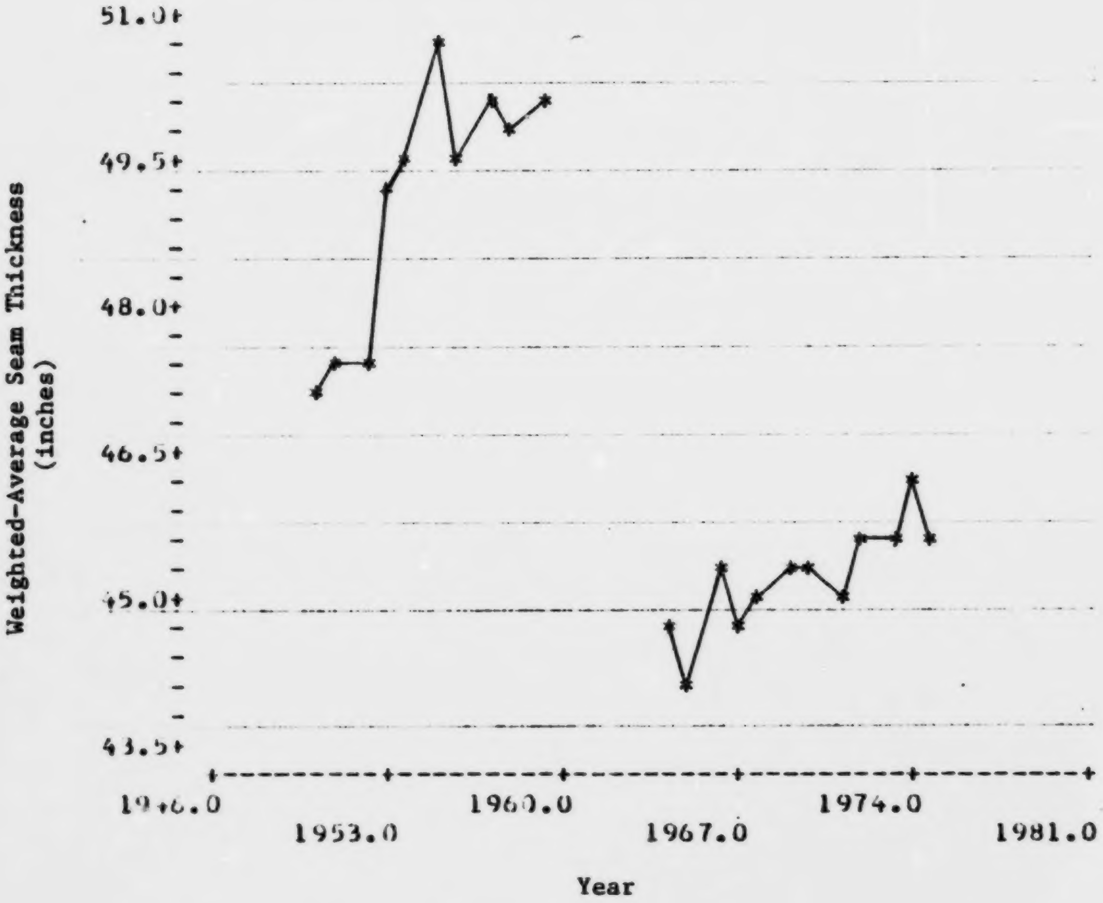


Figure 73. Trend of Weighted-Average Seam Thickness, Estimated in 1964 Through 1975: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

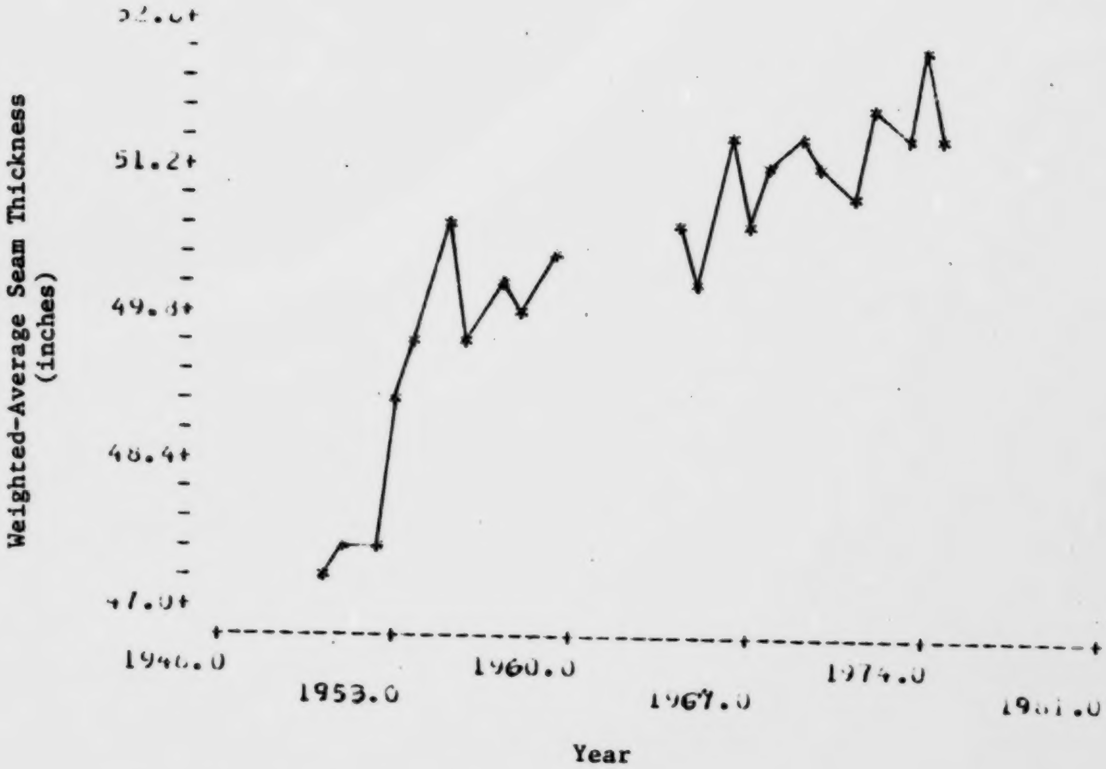


Figure 74. Trend of Adjusted Weighted-Average Seam Thickness: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

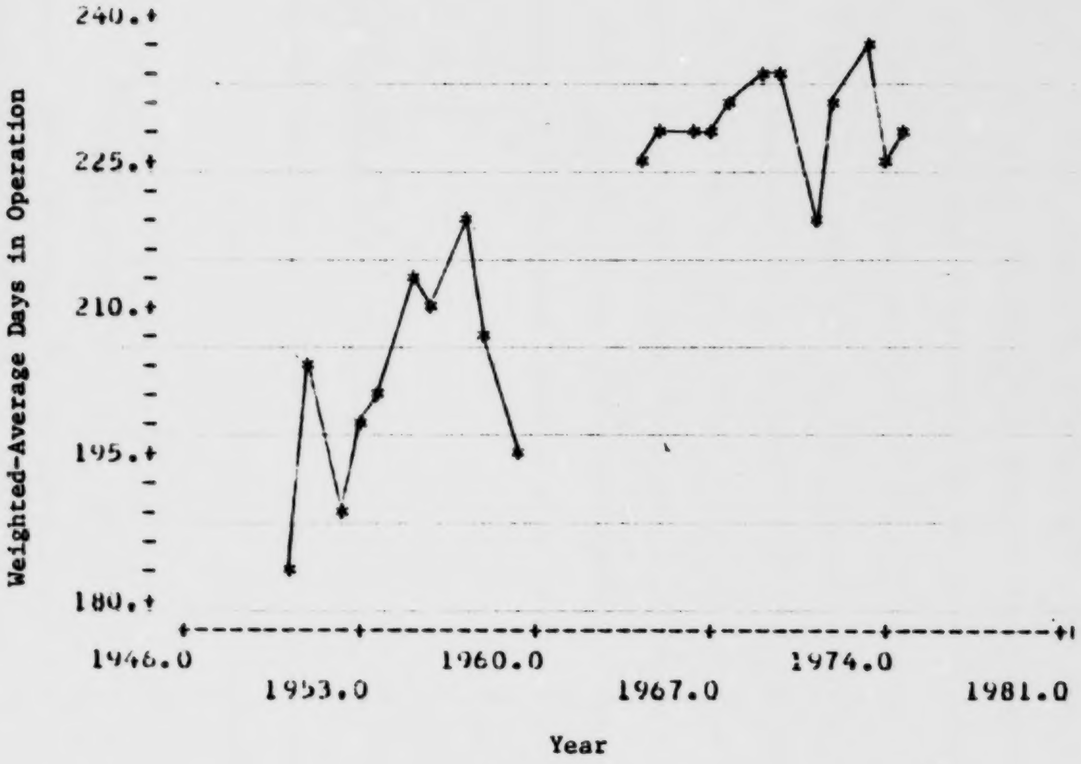


Figure 75. Trend of Weighted-Average Days in Operation: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

shows a gradually increasing trend from 1950 through 1975, although after 1969 the trend appears to level off somewhat. A break in trend from positive to negative in 1969 is significant at the 99.0 percent confidence level. Average production (Figure 76) declines through 1954, rises through 1967, then declines afterward. A break in trend from positive to negative in 1969 is significant at the 99.0 percent confidence level. The actual price of coal in Kentucky (Figure 77) shows a declining trend from 1950 through the late 1960s, then a rising trend through 1975, with especially high increases in 1974 and 1975. A break in trend from negative to positive in 1969 is significant at the 99.0 percent confidence level. Assuming there is no Health and Safety Act in 1970 through 1975, estimates indicate that the price of coal would be decreased by approximately 21.65 percent (Fettig, 1978; see Table 33). The resulting price trends downward through 1970 then upward through 1975 (Figure 78).

Results of Regressions for 1950 Through 1959 and 1964 Through 1975 and for 1950 Through 1975 for Underground Rail-Connected Mines

The results for the OLS regression of the model for the years 1950 through 1959 and 1964 through 1975 follow.

$$
\begin{aligned}
(48)\quad PRY_t = {} & \underset{(12.2191)}{-30.1120} + \underset{(5.93257)\#\#\#\#\#}{30.7799\ AP_t} + \underset{(0.250896)\#\#\#\#\#}{0.805989\ ST_t} + \underset{(0.0437632)\#\#\#}{0.105759\ CM_t} \\
& - \underset{(0.0219295)}{0.0167531\ DO_t} - \underset{(0.0328238)\#\#\#\#\#}{0.103844\ PR_t} - \underset{(0.0202781)\#\#\#\#\#}{0.0674320\ MACT_t}
\end{aligned}
$$

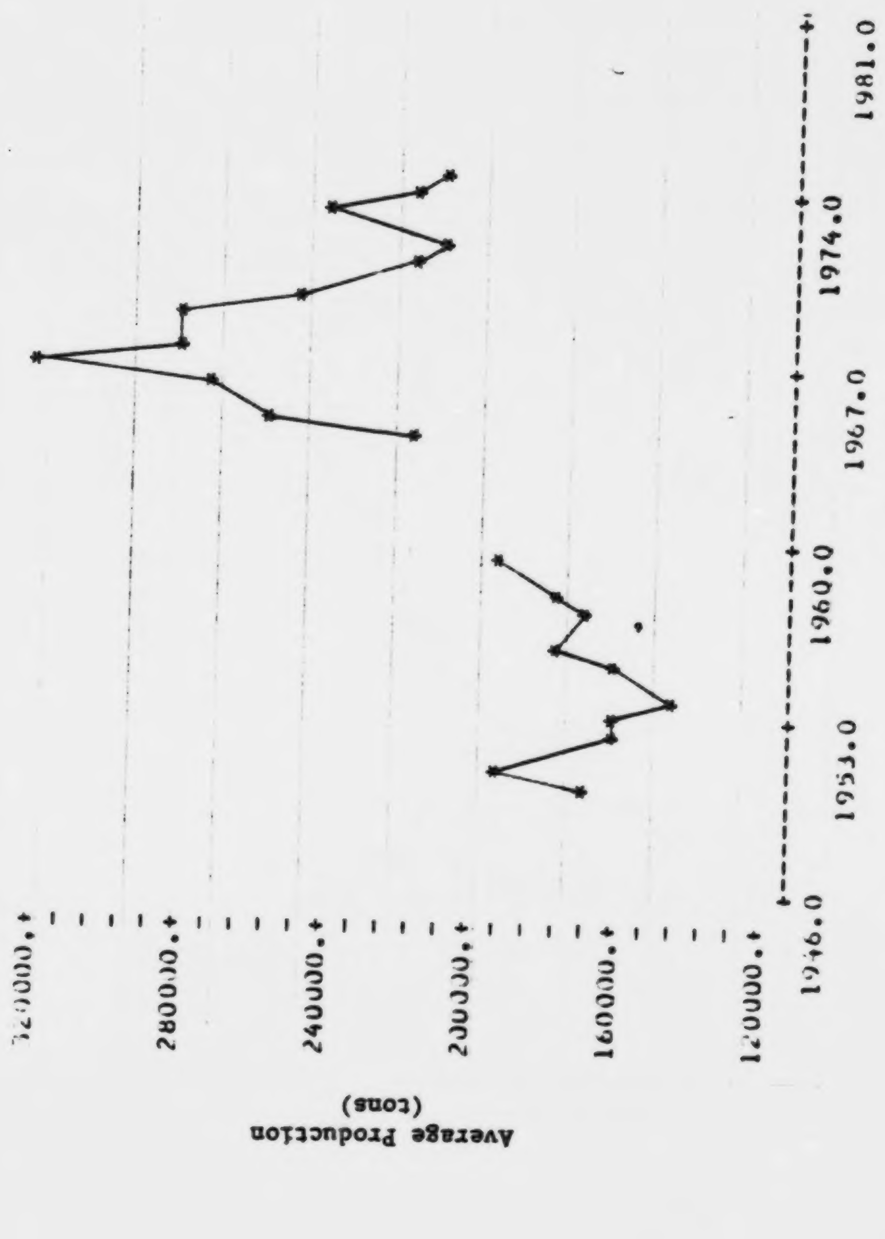


Figure 76. Trend of Average Production: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

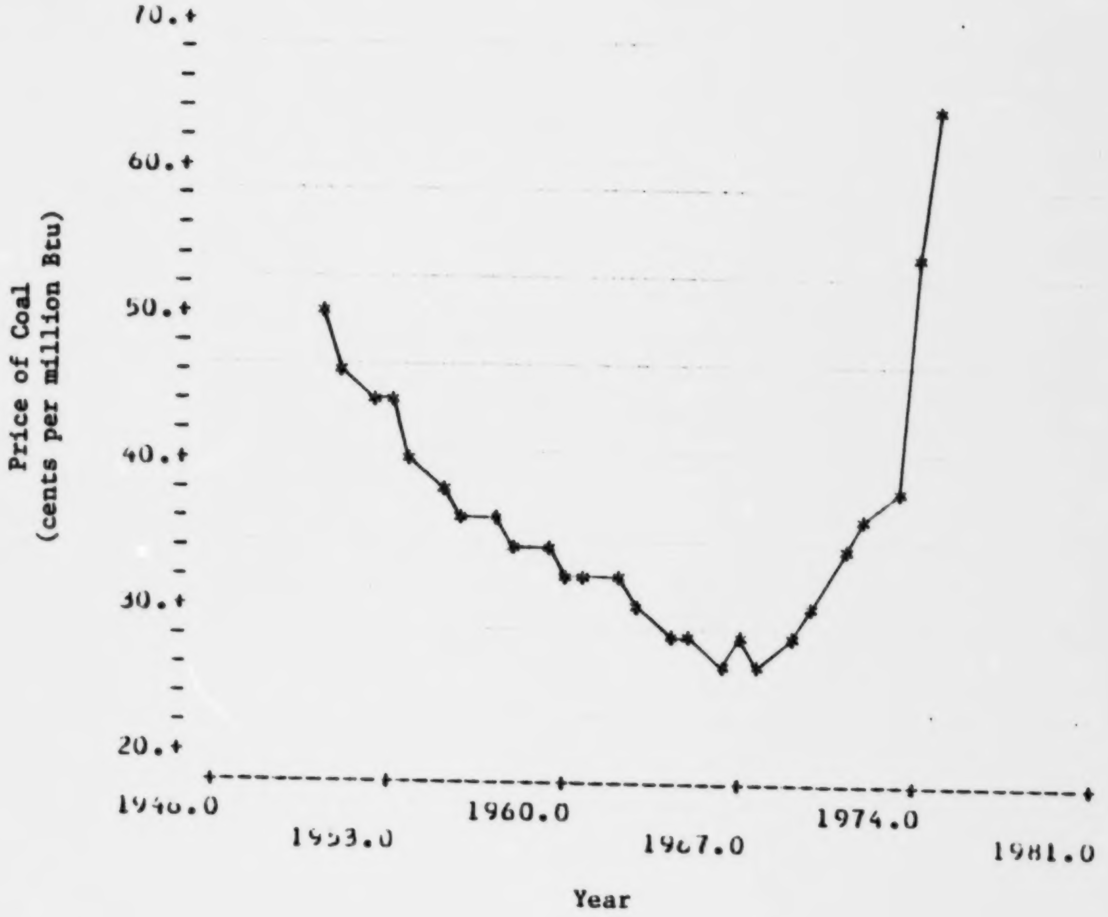


Figure 77. Trend of the Price of Coal: Kentucky (1950 Through 1975)

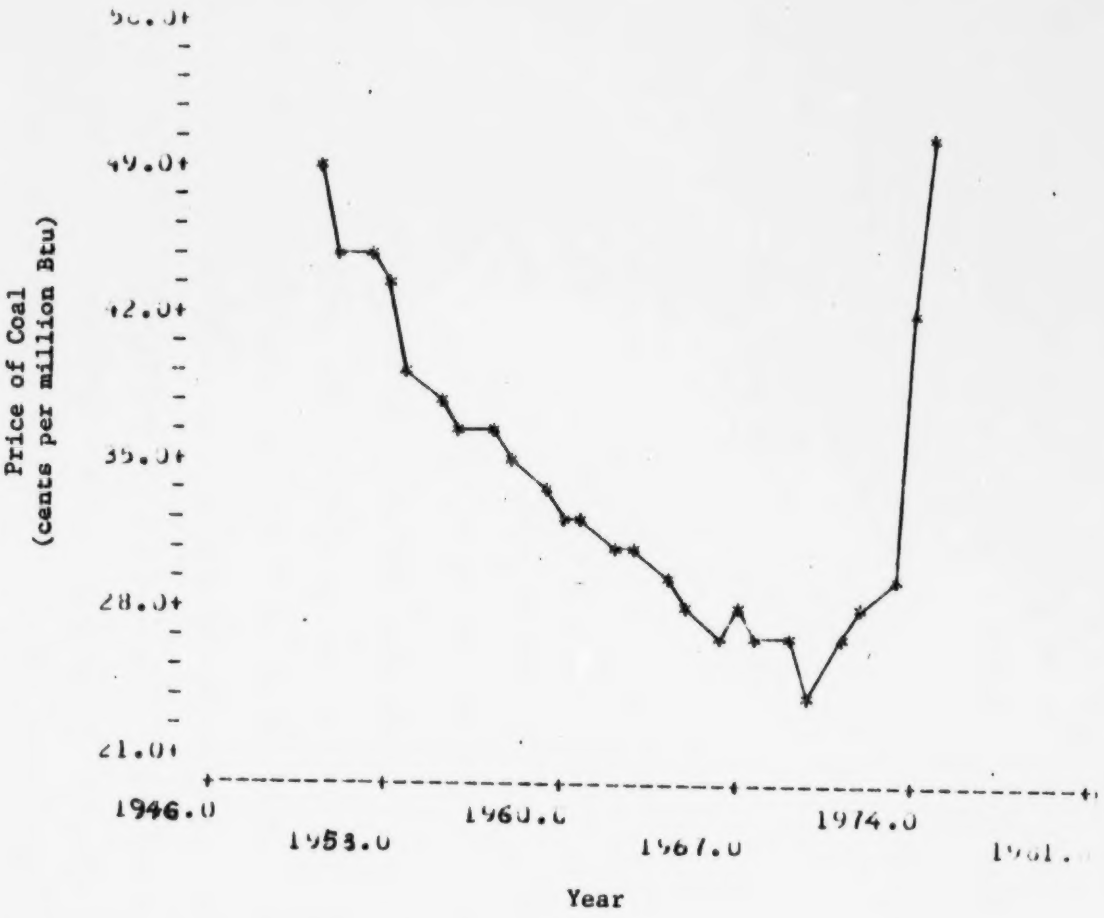


Figure 78. Trend of the Price of Coal Assuming No CMHSA: Kentucky (1950 Through 1975)

$R^2 = 0.9739$

F-statistic (6,15) = 93.3426

Durbin-Watson statistic = 2.1013

Standard error of the regression = 0.642890

Sum of squared residuals = 6.19961.

The results for the OLS regression of the model for the years 1950 through 1975 with estimated data in 1960 through 1963 are:

$$\begin{aligned} \text{(48E)}\ PRY_t = {} & -34.9520 + 31.6397\ AP_t + 0.948754\ ST_t + 0.0947040\ CM_t \\ & (11.9002) \quad (5.83622)\#\#\#\#\#(0.232505)\#\#\#\#\#\ (0.0430538)\#\#\# \\ & - 0.0266767\ DO_t - 0.108143\ PR_t - 0.0674362\ MACT_t \\ & (0.0188534) \quad (0.0322953)\#\#\#\#\#(0.0201335)\#\#\#\#\# \end{aligned}$$

$R^2 = 0.9681$

F-statistic (6,19) = 95.9802

Durbin-Watson statistic = 1.7089

Standard error of the regression = 0.640749

Sum of squared residuals = 7.80062.

For both equations, the coefficients of AP, ST, PR, and MACT are all significant at the 99.5 percent confidence level; the coefficients of CM are significant at the 97.5 percent confidence level. All of these coefficients have expected signs. The coefficients of DO have unexpected signs but are not significant. The coefficients of multiple determination are 0.97, and the equations are significant at the 99.0 percent confidence level. The Durbin-Watson statistics are in the inconclusive region. However, the Hart-von Neumann statistics indicate no autocorrelation in either equation. Pairwise correlation matrices are shown in Tables 35 and 36; correlations are similar with and without

Table 35

Pairwise Correlation Matrix for AP, ST, CM, DO, PR, and MACT: Eastern Kentucky
(1950 Through 1959 and 1964 Through 1975)

	AP	ST	CM	DO	PR	MACT
AP	1.0000	0.56158	0.59018	0.74639	-0.65769	0.089581
ST	0.56158	1.0001	0.81718	0.84687	-0.58880	0.53725
CM	0.59018	0.81718	1.0000	0.76183	-0.32214	0.76192
DO	0.74639	0.84687	0.76183	1.0000	-0.67175	0.41040
PR	-0.65769	-0.58860	-0.32214	-0.67175	1.0000	0.14568
MACT	0.089581	0.53725	0.76192	0.41040	0.14568	1.0000

Table 36

Pairwise Correlation Matrix for AP, ST, CM, DO, PR, and MACT Including Estimated Data for 1960 Through 1963: Eastern Kentucky (1950 Through 1975)

	AP	ST	CM	DO	PR	MACT
AP	1.0000	0.55585	0.59088	0.73899	-0.64025	0.099096
ST	0.55585	1.0001	0.79539	0.80975	-0.59150	0.51178
CM	0.59088	0.79539	1.0000	0.75751	-0.29225	0.76738
DO	0.73899	0.80975	0.75751	1.0000	-0.61948	0.42514
PR	-0.64025	-0.59150	-0.29225	-0.61948	1.0000	0.17116
MACT	0.099096	0.51178	0.76738	0.42514	0.17116	1.0000

estimated data in 1960 through 1963, as would be expected. The largest correlations are between ST and CM and between ST and DO. Plots of actual and fitted values and residuals plots are shown in Figures 79 and 80 for Equations 48 and 48E, respectively. Predicted values and residuals plots are quite similar for the two equations. The residuals plots give no indication of the presence of heteroskedasticity.

The principal components method was used to correct for multicollinearity. The factor loadings for the principal components and the results of the OLS regression using data for 1950 through 1959 and 1964 through 1975 follow:

Variable	Factor Loadings
AP	0.82934
ST	0.90156
CM	0.82749
DO	0.95006
PR	-0.74820

(49) $PRY_t = 10.9789 + 3.56959\, PC_t - 0.0747030\, MACT_t$

(0.198294)(0.193801)**** (0.0118614)#####

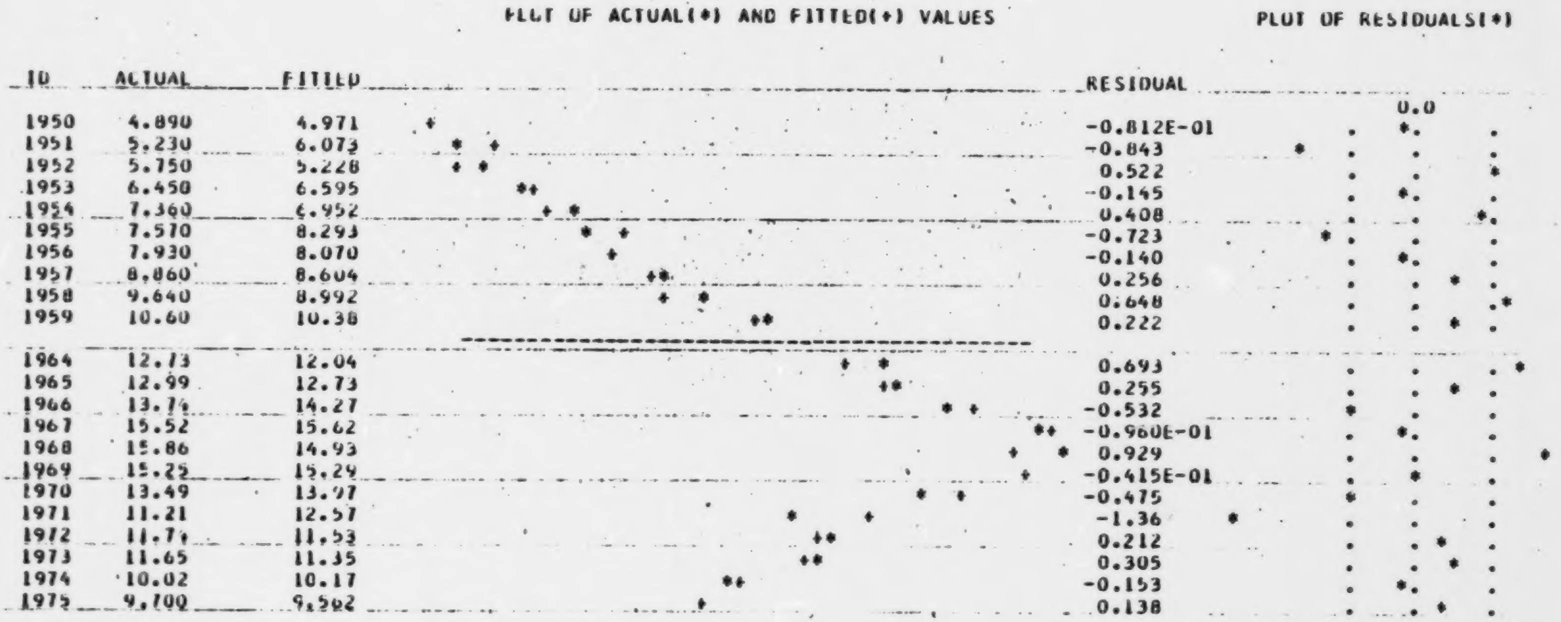
$R^2 = 0.9472$

F-statistic (2,10) = 170.382

Durbin-Watson statistic = 1.5455

Standard error of the regression = 0.812798

Sum of squared residuals = 12.5522 .



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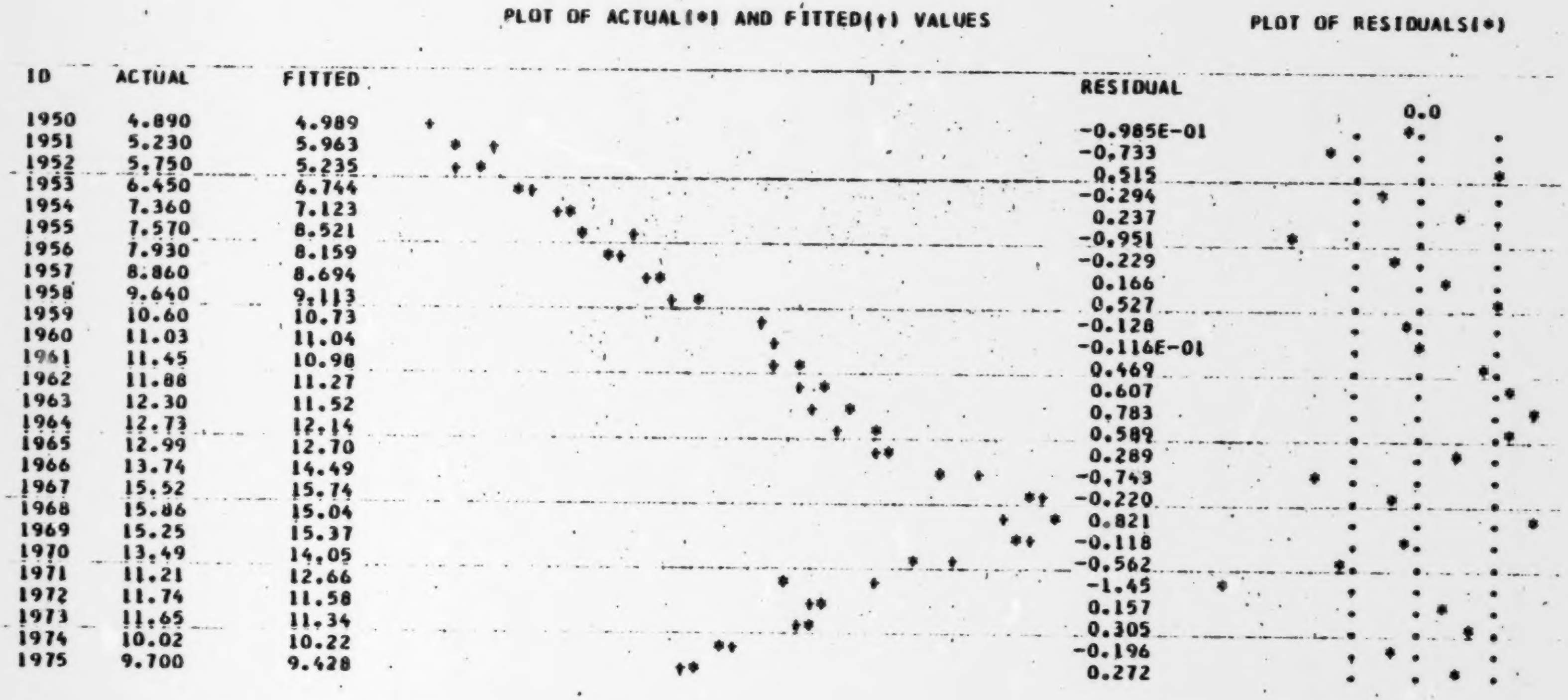
                         PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)

 ID    ACTUAL     FITTED                                          RESIDUAL
                                                                                      0.0
1950   4.890      4.971                                           -0.812E-01
1951   5.230      6.073                                           -0.843
1952   5.750      5.228                                            0.522
1953   6.450      6.595                                           -0.145
1954   7.360      6.952                                            0.408
1955   7.570      8.293                                           -0.723
1956   7.930      8.070                                           -0.140
1957   8.860      8.604                                            0.256
1958   9.640      8.992                                            0.648
1959   10.60      10.38                                            0.222

1964   12.73      12.04                                            0.693
1965   12.99      12.73                                            0.255
1966   13.74      14.27                                           -0.532
1967   15.52      15.62                                           -0.960E-01
1968   15.86      14.93                                            0.929
1969   15.25      15.29                                           -0.415E-01
1970   13.49      13.97                                           -0.475
1971   11.21      12.57                                           -1.36
1972   11.74      11.53                                            0.212
1973   11.65      11.35                                            0.305
1974   10.02      10.17                                           -0.153
1975   9.700      9.562                                            0.138
```

Figure 79. Plots for Productivity Model, 1950 Through 1959 and 1964 Through 1975: Eastern Kentucky (OLS)



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                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID     ACTUAL     FITTED                               RESIDUAL
                                                                          0.0
1950    4.890      4.989                              -0.985E-01
1951    5.230      5.963                              -0.733
1952    5.750      5.235                               0.515
1953    6.450      6.744                              -0.294
1954    7.360      7.123                               0.237
1955    7.570      8.521                              -0.951
1956    7.930      8.159                              -0.229
1957    8.860      8.694                               0.166
1958    9.640      9.113                               0.527
1959   10.60      10.73                               -0.128
1960   11.03      11.04                               -0.116E-01
1961   11.45      10.98                                0.469
1962   11.88      11.27                                0.607
1963   12.30      11.52                                0.783
1964   12.73      12.14                                0.589
1965   12.99      12.70                                0.289
1966   13.74      14.49                               -0.743
1967   15.52      15.74                               -0.220
1968   15.86      15.04                                0.821
1969   15.25      15.37                               -0.118
1970   13.49      14.05                               -0.562
1971   11.21      12.66                               -1.45
1972   11.74      11.58                                0.157
1973   11.65      11.34                                0.305
1974   10.02      10.22                               -0.196
1975    9.700      9.428                               0.272
```

Figure 80. Plots for Productivity Model, 1950 Through 1975: Eastern Kentucky (OLS)

The pairwise correlation matrix is:

	PC	MACT
PC	1.0000	0.40299
MACT	0.40299	1.0000

Using data for 1950 through 1975, including estimates for 1960 through 1963, the results are:

Variable	Factor Loadings
AP	0.83104
ST	0.89455
CM	0.82399
DO	0.93630
PR	-0.72975

$$\text{(49E)}\quad PRY_t = 11.1245 + 3.29846\,PC_t - 0.0805202\,MACT_t$$
$$(0.185017)(0.184333){*}{*}{*}{*}(0.0120712)\#\#\#\#\#$$

$R^2 = 0.9331$

F-statistic (2,23) = 160.284

Durbin-Watson statistic = 1.2049

Standard error of the regression = 0.843133

Sum of squared residuals = 16.3501 .

The pairwise correlation matrix is:

	PC	MACT
PC	1.0000	0.40392
MACT	0.40392	1.0000

For both equations, the coefficients of the principal component and the Mine-Act variable are significant at the 99.0 and 99.5 percent confidence level, respectively. The Mine-Act variables have the expected signs. Both equations are significant at the 99.0 percent confidence level. The R^2s are 0.947 and 0.933 for Equation 49 and 49E, respectively. Both equations are significant at the 99.0 percent confidence level. The Durbin-Watson statistic indicates no autocorrelation in Equation 49. That of Equation 49E, however, indicates positive autocorrelation (95.0 percent confidence level). The pairwise correlation matrices indicate the degree of multicollinearity is low. Plots of actual and fitted values and plots of the residuals are presented in Figures 81 and 82. The residuals plots give no indication of the presence of heteroskedasticity. Again, results are very similar for the two equations.

Correcting for both multicollinearity and autocorrelation in Equation 49E using principal components and the Cochrane-Orcutt iterative method yields the following results:

$$\text{(49E-A)}\quad PRY_t = \underset{(1.21779)}{11.7040} + \underset{(0.536031)^{****}}{1.56599}\, PC_t - \underset{(0.0241560)\#\#}{0.0471155}\, MACT_t$$

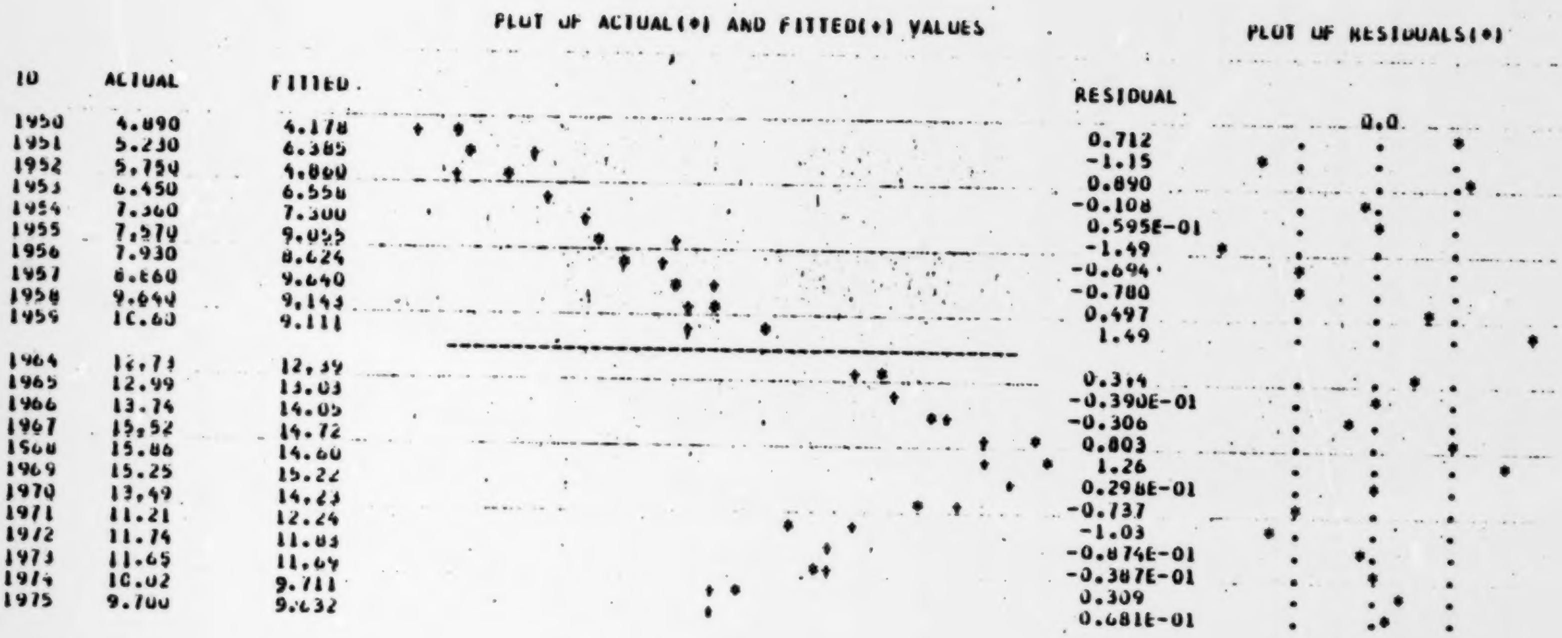
$R^2 = 0.9459$

F-statistic (2,22) = 192.446

Durbin-Watson statistic = 1.5853

Standard error of the regression = 0.719555

Sum of squared residuals = 11.3907.



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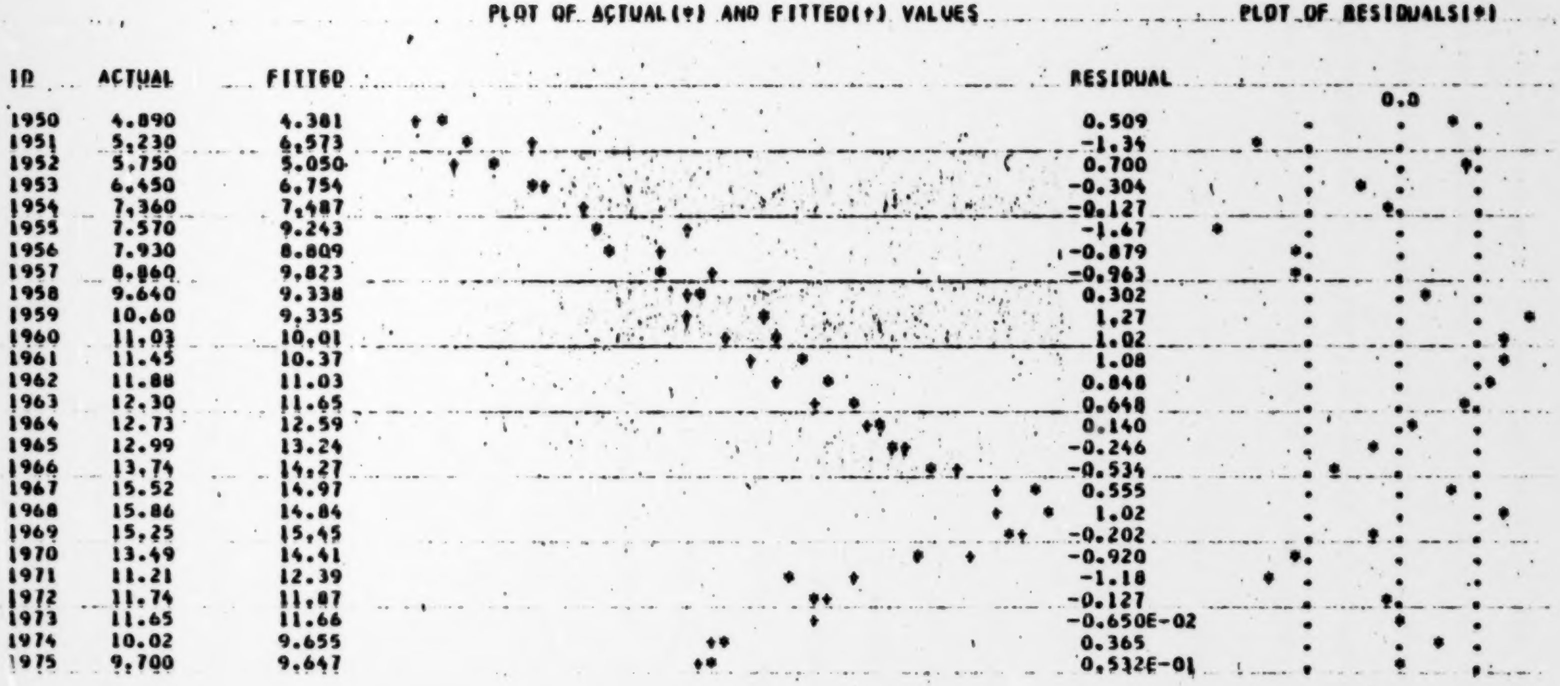
                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
 ID      ACTUAL      FITTED
                                                                 RESIDUAL              0.0
1950      4.890       4.178                                        0.712
1951      5.230       6.385                                       -1.15
1952      5.750       4.860                                        0.890
1953      6.450       6.558                                       -0.108
1954      7.360       7.300                                        0.595E-01
1955      7.570       9.055                                       -1.49
1956      7.930       8.624                                       -0.694
1957      8.860       9.640                                       -0.780
1958      9.640       9.143                                        0.497
1959     10.60        9.111                                        1.49

1964     12.73       12.39                                         0.344
1965     12.99       13.03                                        -0.390E-01
1966     13.74       14.05                                        -0.306
1967     15.52       14.72                                         0.803
1968     15.86       14.60                                         1.26
1969     15.25       15.22                                         0.298E-01
1970     13.49       14.23                                        -0.737
1971     11.21       12.24                                        -1.03
1972     11.74       11.83                                        -0.874E-01
1973     11.65       11.69                                        -0.387E-01
1974     10.02        9.711                                        0.309
1975      9.700       9.632                                        0.681E-01
```

Figure 81. Plots for Productivity Model Using Principal Components, 1950 Through 1959 and 1964 Through 1975: Eastern Kentucky (OLS)



```
                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID      ACTUAL      FITTED                                RESIDUAL
                                                                              0.0
1950    4.890       4.381                                 0.509
1951    5.230       6.573                                 -1.34
1952    5.750       5.050                                 0.700
1953    6.450       6.754                                 -0.304
1954    7.360       7.487                                 -0.127
1955    7.570       9.243                                 -1.67
1956    7.930       8.809                                 -0.879
1957    8.860       9.823                                 -0.963
1958    9.640       9.338                                 0.302
1959    10.60       9.335                                 1.27
1960    11.03       10.01                                 1.02
1961    11.45       10.37                                 1.08
1962    11.88       11.03                                 0.848
1963    12.30       11.65                                 0.648
1964    12.73       12.59                                 0.140
1965    12.99       13.24                                 -0.246
1966    13.74       14.27                                 -0.534
1967    15.52       14.97                                 0.555
1968    15.86       14.84                                 1.02
1969    15.25       15.45                                 -0.202
1970    13.49       14.41                                 -0.920
1971    11.21       12.39                                 -1.18
1972    11.74       11.87                                 -0.127
1973    11.65       11.66                                 -0.650E-02
1974    10.02       9.655                                 0.365
1975    9.700       9.647                                 0.532E-01
```

Figure 82. Plots for Productivity Model Using Principal Components, 1950 Through 1975: Eastern Kentucky (OLS)

There is no autocorrelation; however, the coefficient of the Mine-Act variable is now significant at a lower confidence level (95.0 percent rather than 99.5 percent). Appropriate plots are shown in Figure 83.

The results for the OLS regression of the model with seam thickness eliminated using data for 1950 through 1959 and 1964 through 1975 are:

$$
\begin{aligned}
(50)\quad PRY_t = {} & 6.21866 + 23.9092\,AP_t + 0.167934\,CM_t + 0.0128742\,DO_t \\
& (5.81993)\quad (6.96112)\#\#\#\#\#(0.0493762)\#\#\#\#\#(0.0250284) \\
& - 0.148392\,PR_t - 0.0661691\,MACT_t \\
& (0.0374252)\#\#\#\#\#(0.0255044)\#\#\#\#
\end{aligned}
$$

$R^2 = 0.9560$

F-statistic (5,16) = 69.4774

Durbin-Watson statistic = 1.3095

Standard error of the regression = 0.808736

Sum of squared residuals = 10.4649 .

Results for the OLS regression of the model with seam thickness eliminated using estimated data in 1960 through 1963 are:

$$
\begin{aligned}
(50E)\quad PRY_t = {} & 10.6593 + 23.6202\,AP_t + 0.172257\,CM_t + 0.00247059\,DO_t \\
& (5.45186)\quad (7.33700)\#\#\#\#\#(0.0515784)\#\#\#\#\#(0.0238932) \\
& - 0.176120\,PR_t - 0.0647961\,MACT_t \\
& (0.0369392)\#\#\#\#\#(0.0268668)\#\#\#
\end{aligned}
$$

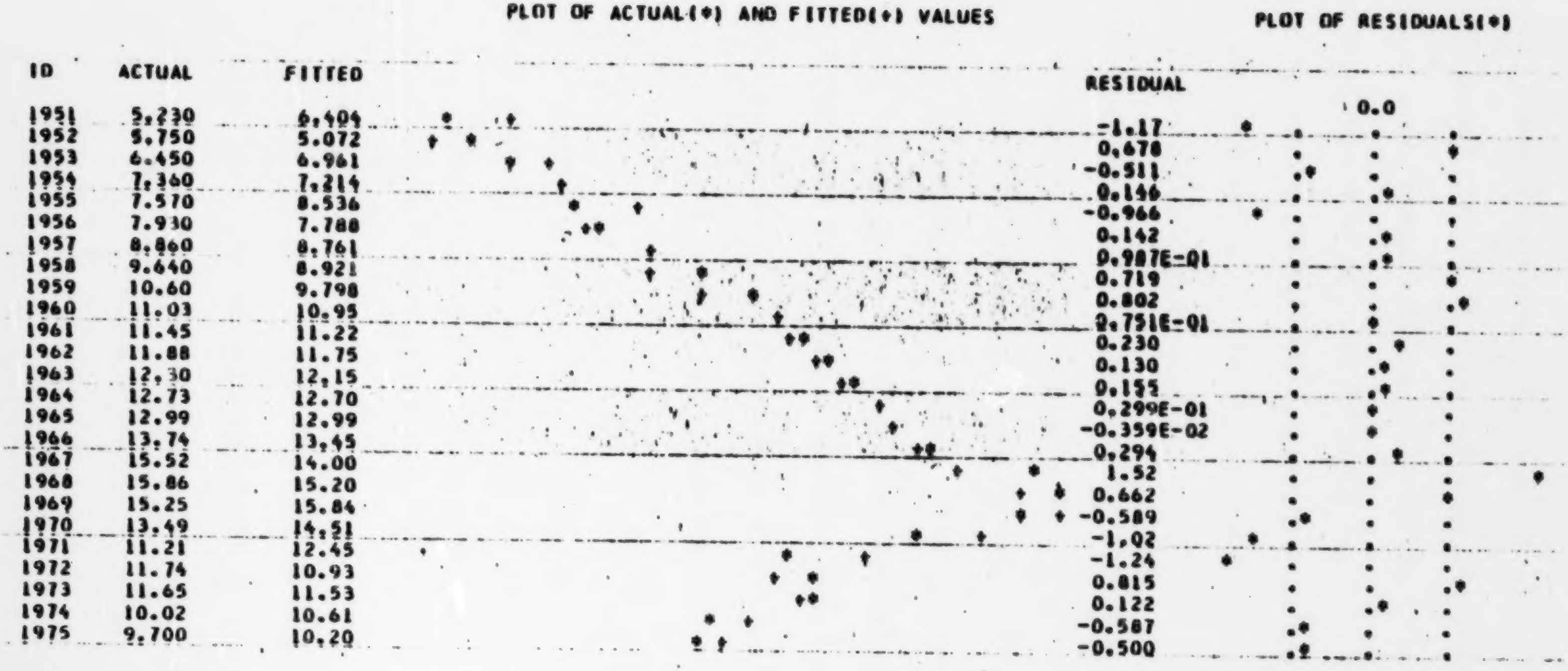
$R^2 = 0.9401$

F-statistic (5,20) = 62.7448

Durbin-Watson statistic = 0.9452

Standard error of the regression = 0.855479

Sum of squared residuals = 14.6369 .



PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(*)

ID	ACTUAL	FITTED	RESIDUAL
1951	5.230	6.404	-1.17
1952	5.750	5.072	0.678
1953	6.450	6.961	-0.511
1954	7.360	7.214	0.146
1955	7.570	8.536	-0.966
1956	7.930	7.788	0.142
1957	8.860	8.761	0.987E-01
1958	9.640	8.921	0.719
1959	10.60	9.798	0.802
1960	11.03	10.95	0.751E-01
1961	11.45	11.22	0.230
1962	11.88	11.75	0.130
1963	12.30	12.15	0.155
1964	12.73	12.70	0.299E-01
1965	12.99	12.99	-0.359E-02
1966	13.74	13.45	0.294
1967	15.52	14.00	1.52
1968	15.86	15.20	0.662
1969	15.25	15.84	-0.589
1970	13.49	14.51	-1.02
1971	11.21	12.45	-1.24
1972	11.74	10.93	0.815
1973	11.65	11.53	0.122
1974	10.02	10.61	-0.587
1975	9.700	10.20	-0.500

Figure 83. Plots for Productivity Model Using Principal Components, 1950 Through 1975: Eastern Kentucky (CORC)

Coefficients of AP, CM, and PR are all significant at the 99.5 percent confidence level and have the expected signs. The coefficient of MACT is significant at the 99.0 percent confidence level in Equation 50 (97.5 percent level in Equation 50E); in both equations the coefficient of MACT has the expected sign. The coefficients of DO are not significant; the sign is unexpectedly negative in Equation 50E. Both equations are significant at the 99.0 percent confidence level. Equation 50 explains over 95.0 percent of the variation; Equation 50E explains over 94.0 percent. Both equations have the problem of positive autocorrelation (95.0 percent confidence level). Plots of actual and fitted values and plots of the residuals are presented in Figures 84 and 85. No sign of heteroskedasticity is evident in either residuals plot. The results of the two equations are quite similar.

Correcting for autocorrelation with the Cochrane-Orcutt iterative method yields the following results using data for 1950 through 1959 and 1964 through 1975.

$$
\begin{array}{llllll}
(51)\ PRY_t = & 9.98247 & + 25.4205\ AP_t & + 0.156193\ CM_t & - 0.00590039\ DO_t \\
 & (5.53082) & (8.43788)\#\#\#\#\# & (0.0515010)\#\#\#\#\# & (0.0249988) \\
 & - 0.147466\ PR_t & - 0.0501639\ MACT_t & & \\
 & (0.0437339)\#\#\#\#\# & (0.0280976)\#\# & &
\end{array}
$$

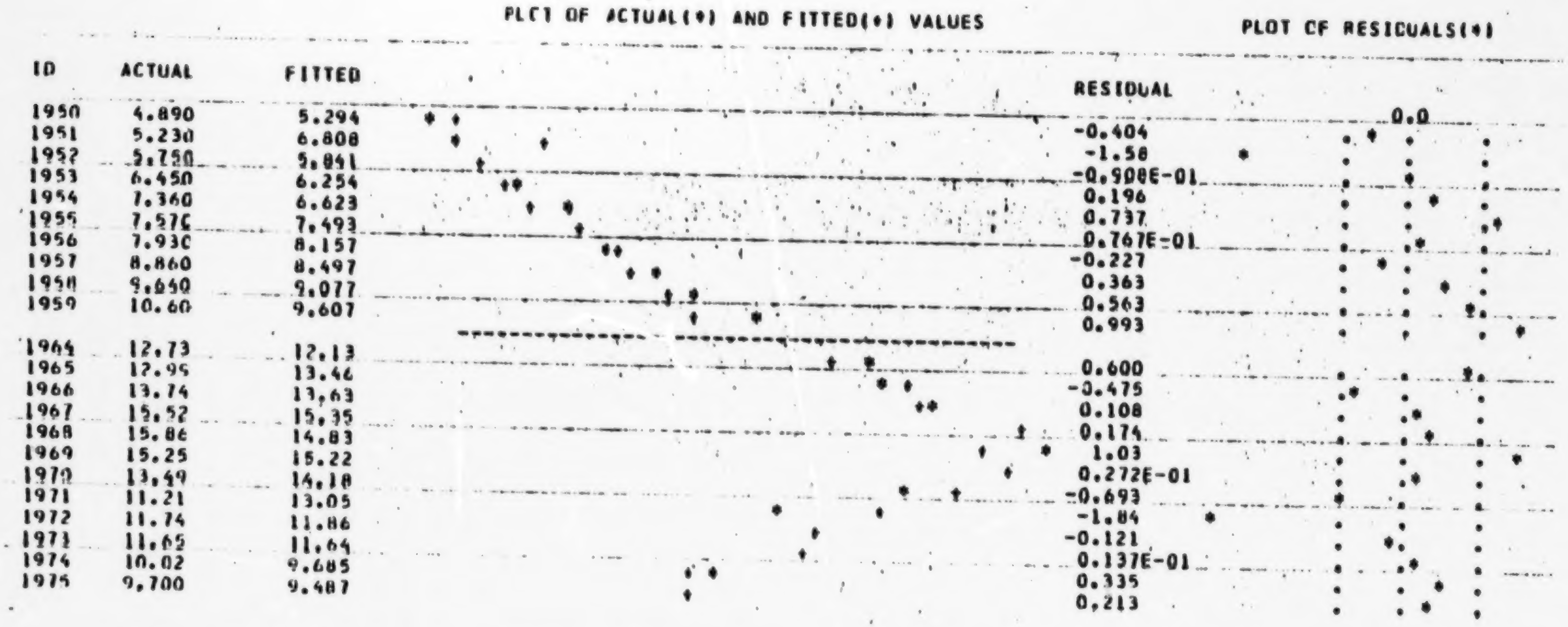
$R^2 = 0.9585$

F-statistic (5,14) = 64.7233

Durbin-Watson statistic = 1.8369

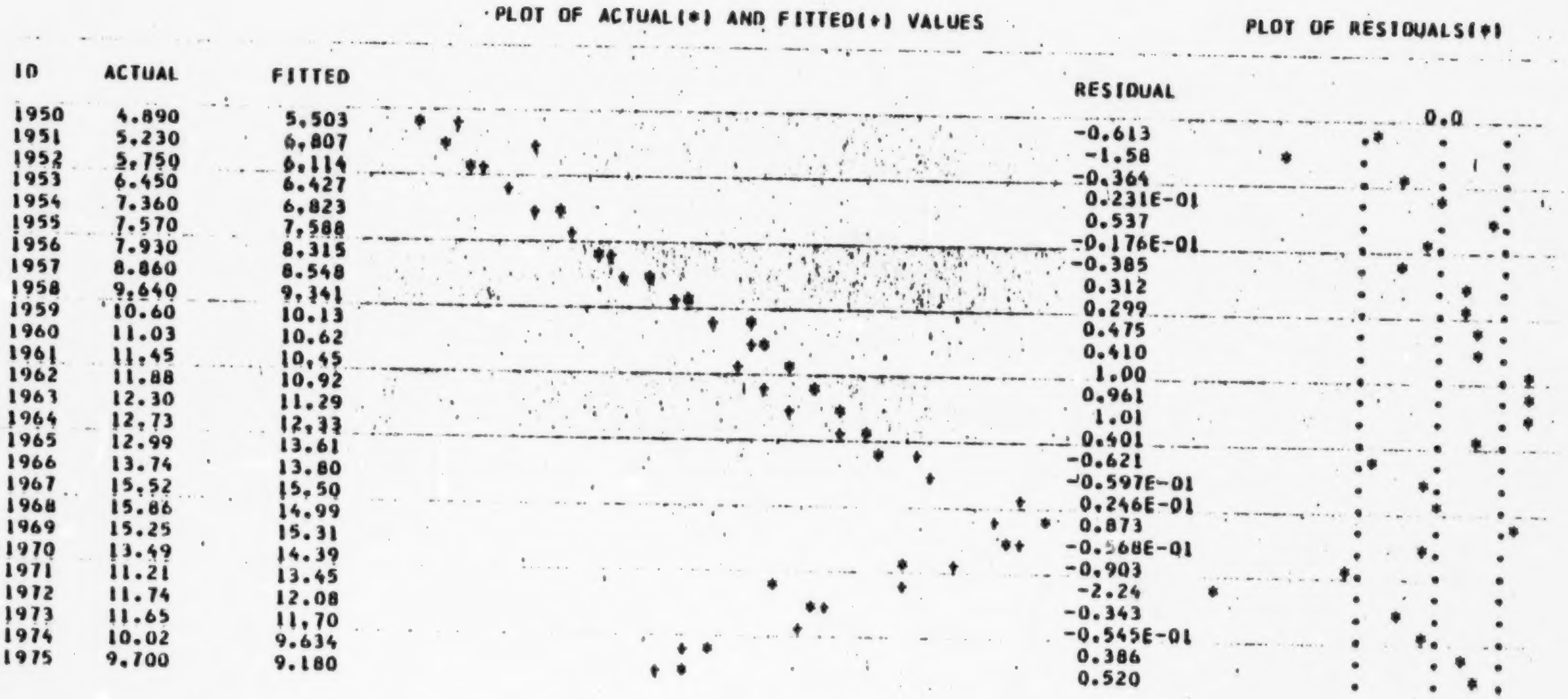
Standard error of the regression = 0.772693

Sum of squared residuals = 8.35877.



ID	ACTUAL	FITTED	RESIDUAL
1950	4.890	5.294	-0.404
1951	5.230	6.808	-1.58
1952	5.750	5.841	-0.908E-01
1953	6.450	6.254	0.196
1954	7.360	6.623	0.737
1955	7.570	7.493	0.767E-01
1956	7.930	8.157	-0.227
1957	8.860	8.497	0.363
1958	9.640	9.077	0.563
1959	10.60	9.607	0.993
1964	12.73	12.13	0.600
1965	12.99	13.46	-0.475
1966	13.74	13.63	0.108
1967	15.52	15.35	0.174
1968	15.86	14.83	1.03
1969	15.25	15.22	0.272E-01
1970	13.49	14.18	-0.693
1971	11.21	13.05	-1.84
1972	11.74	11.86	-0.121
1973	11.65	11.64	0.137E-01
1974	10.02	9.685	0.335
1975	9.700	9.487	0.213

Figure 84. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1959 and 1964 Through 1975: Eastern Kentucky (OLS)



```
                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                   RESIDUAL
                                                                              0.0
1950     4.890       5.503                                   -0.613
1951     5.230       6.807                                   -1.58
1952     5.750       6.114                                   -0.364
1953     6.450       6.427                                    0.231E-01
1954     7.360       6.823                                    0.537
1955     7.570       7.588                                   -0.176E-01
1956     7.930       8.315                                   -0.385
1957     8.860       8.548                                    0.312
1958     9.640       9.341                                    0.299
1959    10.60       10.13                                     0.475
1960    11.03       10.62                                     0.410
1961    11.45       10.45                                     1.00
1962    11.88       10.92                                     0.961
1963    12.30       11.29                                     1.01
1964    12.73       12.33                                     0.401
1965    12.99       13.61                                    -0.621
1966    13.74       13.80                                    -0.597E-01
1967    15.52       15.50                                     0.246E-01
1968    15.86       14.99                                     0.873
1969    15.25       15.31                                    -0.568E-01
1970    13.49       14.39                                    -0.903
1971    11.21       13.45                                    -2.24
1972    11.74       12.08                                    -0.343
1973    11.65       11.70                                    -0.545E-01
1974    10.02        9.634                                    0.386
1975     9.700       9.180                                    0.520
```

Figure 85. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1975: Eastern Kentucky (OLS)

Using data from 1950 through 1975, with estimated data for 1960 through 1963, the results of the Cochrane-Orcutt method are:

$$\begin{array}{ll} \text{(51E)}\ PRY_t = & 10.2595 + 20.5678\ AP_t + 0.0596277\ CM_t - 0.00283998\ DO_t \\ & (4.67968)\ \ (7.18977)\#\#\#\#\#(0.0737378)\qquad (0.0195053) \\ & - 0.0921676\ PR_t - 0.0288560\ MACT_t \\ & \quad (0.0571550)\#\qquad (0.0263728) \end{array}$$

$R^2 = 0.9558$

F-statistic (5,19) = 82.2183

Durbin-Watson statistic = 1.8972

Standard error of the regression = 0.699878

Sum of squared residuals = 9.30677 .

In Equation 51, the coefficient of MACT is significant at the 95.0 percent confidence level; the coefficients of AP, CM, and PR are significant at the 99.5 percent confidence level. The coefficient of DO has an unexpected sign but is not significant. Other coefficients have the expected sign. In Equation 51E, the coefficients of AP and PR are significant at the 99.5 percent and 90.0 percent confidence level, respectively. The coefficients of CM, DO, and MACT are not significant. All coefficients except that of DO have the expected signs. Both of the equations are significant at the 99.0 percent confidence level, and almost 96.0 percent of the variation is explained. For Equation 51, the Durbin-Watson statistic falls in the inconclusive region; however, the Hart-von Neumann statistic indicates no autocorrelation. The Durbin-Watson statistic for Equation 51E indicates no autocorrelation. Plots of actual and fitted values and plots of the residuals are presented in Figures 86 and 87. The residuals plots do not indicate the presence of heteroskedasticity. The results of the two equations are similar.

A comparison of results in Equations 48--with ST--and 51--without ST -- reveal that the seam-thickness variable is significant at a 95.0 percent confidence level. The appropriate F-statistic for the test is $5.23_{(1,15)}$.

Again, the method of principal components was used to correct for multicollinearity. The factor loadings for the principal component and the results of the ordinary least squares regression using data for 1950 through 1959 and 1964 through 1975 follow.

Variable	Factor Loadings
AP	0.88613
CM	0.78714
DO	0.94144
PR	-0.77586

$$(52)\quad PRY_t = 10.8274 + 3.44404\ PC_t - 0.0560546\ MACT_t$$
$$(0.212216)(0.202480)^{****}(0.0123925)^{\#\#\#\#\#}$$

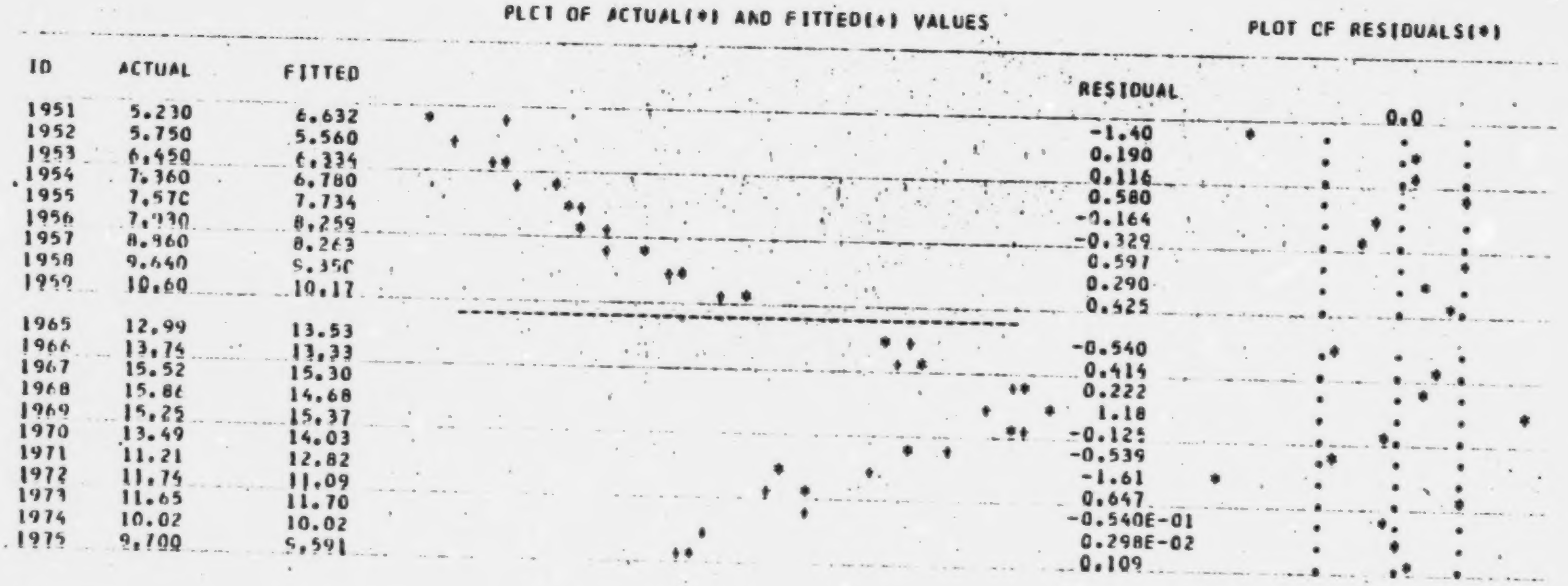
$R^2 = 0.9386$

F-statistic (2,19) = 145.307

Durbin-Watson statistic = 1.5090

Standard error of the regression = 0.876155

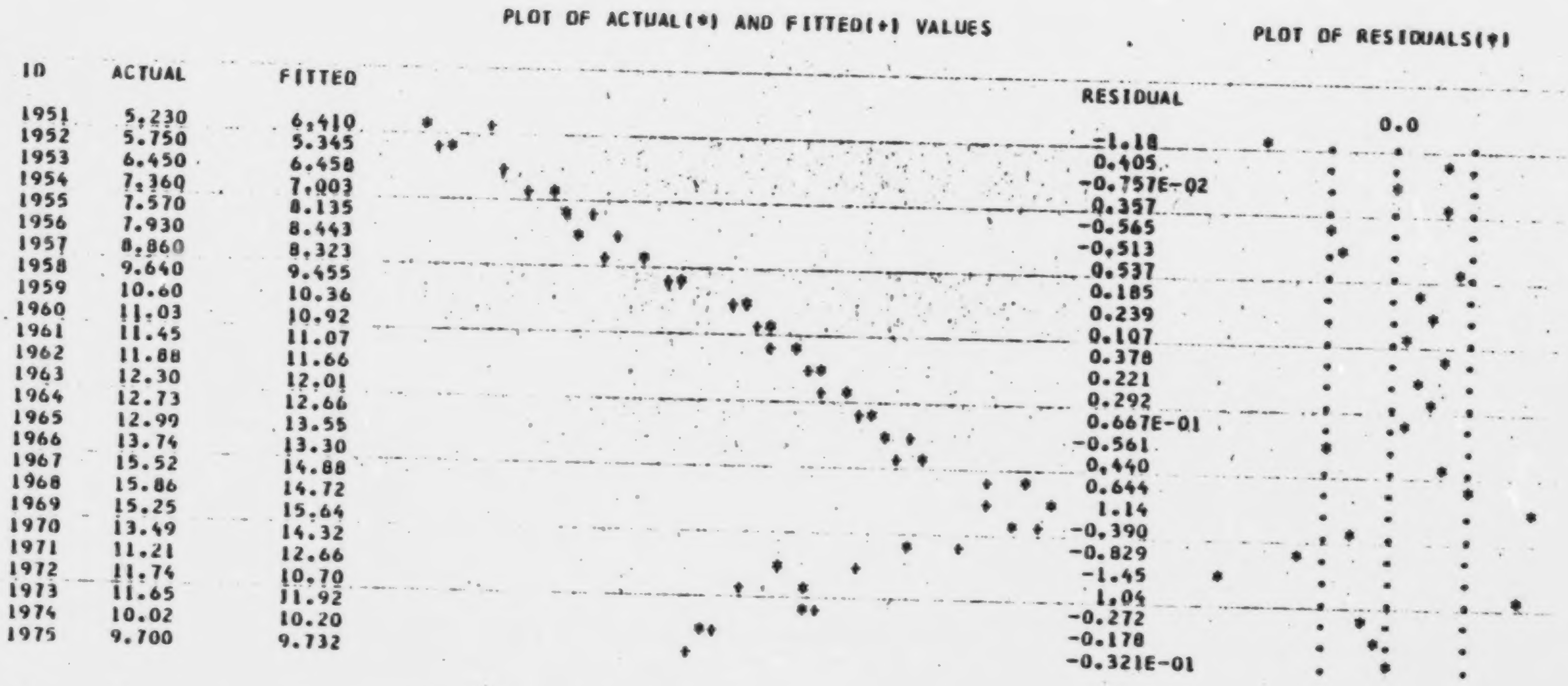
Sum of squared residuals = 14.5853 .



```
                        PLOT OF ACTUAL(*) AND FITTED(+) VALUES                PLOT OF RESIDUALS(*)
ID      ACTUAL        FITTED
                                                                  RESIDUAL
1951     5.230         6.632                                        -1.40
1952     5.750         5.560                                         0.190
1953     6.450         6.334                                         0.116
1954     7.360         6.780                                         0.580
1955     7.570         7.734                                        -0.164
1956     7.930         8.259                                        -0.329
1957     8.960         8.263                                         0.597
1958     9.640         9.350                                         0.290
1959    10.60         10.17                                          0.425

1965    12.99         13.53                                         -0.540
1966    13.74         13.33                                          0.414
1967    15.52         15.30                                          0.222
1968    15.86         14.68                                          1.18
1969    15.25         15.37                                         -0.125
1970    13.49         14.03                                         -0.539
1971    11.21         12.82                                         -1.61
1972    11.74         11.09                                          0.647
1973    11.65         11.70                                         -0.540E-01
1974    10.02         10.02                                          0.298E-02
1975     9.700         9.591                                         0.109
```

Figure 86. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1959 and 1964 Through 1975: Eastern Kentucky (CORC)



```
                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES             PLOT OF RESIDUALS(*)
 ID      ACTUAL      FITTED
                                                                   RESIDUAL
1951     5.230       6.410                                                          0.0
1952     5.750       5.345                                          -1.18
1953     6.450       6.458                                           0.405
1954     7.360       7.003                                          -0.757E-02
1955     7.570       8.135                                           0.357
1956     7.930       8.443                                          -0.565
1957     8.860       8.323                                          -0.513
1958     9.640       9.455                                           0.537
1959    10.60       10.36                                            0.185
1960    11.03       10.92                                            0.239
1961    11.45       11.07                                            0.107
1962    11.88       11.66                                            0.378
1963    12.30       12.01                                            0.221
1964    12.73       12.66                                            0.292
1965    12.99       13.55                                            0.667E-01
1966    13.74       13.30                                           -0.561
1967    15.52       14.88                                            0.440
1968    15.86       14.72                                            0.644
1969    15.25       15.64                                            1.14
1970    13.49       14.32                                           -0.390
1971    11.21       12.66                                           -0.829
1972    11.74       10.70                                           -1.45
1973    11.65       11.92                                            1.04
1974    10.02       10.20                                           -0.272
1975     9.700       9.732                                          -0.178
                                                                    -0.321E-01
```

Figure 87. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1975: Eastern Kentucky (CORC)

The pairwise correlation matrix is:

	PC	MACT
PC	1.0000	0.32922
MACT	0.32922	1.0000

Results using estimated data in 1960 through 1963 are:

Variable	Factor Loadings
AP	0.88809
CM	0.78809
DO	0.93298
PR	-0.74825

$$\text{(52E)}\quad PRY_t = \underset{(0.213964)}{11.0071} + \underset{(0.208397)^{****}}{3.16578}\, PC_t - \underset{(0.0136471)^{\#\#\#\#\#}}{0.0634481}\, MACT_t$$

$R^2 = 0.9095$

F-statistic (2,23) = 115.529

Durbin-Watson statistic = 1.0044

Standard error of the regression = 0.980476

Sum of squared residuals = 22.1107.

The pairwise correlation matrix is:

	PC	MACT
PC	1.0000	0.33849
MACT	0.33849	1.0000

For both equations the coefficients of the principal components and the Mine-Act variable are significant at the 99.0 and 99.5 percent confidence level, respectively. The Mine-Act variables have the expected signs.

The equations are significant at the 99.0 percent confidence level; almost 94.0 percent of the variance is explained in Equation 52 and almost 91.0 percent is explained in Equation 52E. For Equation 52 the Durbin-Watson statistic is in the inconclusive region but the Hart-von Neumann test indicates there is no autocorrelation. For Equation 52E, the Durbin-Watson statistic indicates positive correlation (95.0 percent confidence level). The degree of multicollinearity is low, as indicated by the pairwise correlation matrices. Plots of actual and fitted values and plots of the residuals are presented in Figures 88 and 89. The residuals plots give no indication of the presence of heteroskedasticity. Again, the results of the two regressions are similar.

To correct for positive autocorrelation and multicollinearity in the regression using estimated data in 1960 through 1963, the Cochrane-Orcutt technique and a principal component were used. The results are:

$$\text{(52E-A)}\ PRY_t = \underset{(1.16203)}{11.8181} + \underset{(0.457424)^{****}}{1.37971}\ PC_t - \underset{(0.0237419)\#}{0.0384648}\ MACT_t$$

$R^2 = 0.9467$

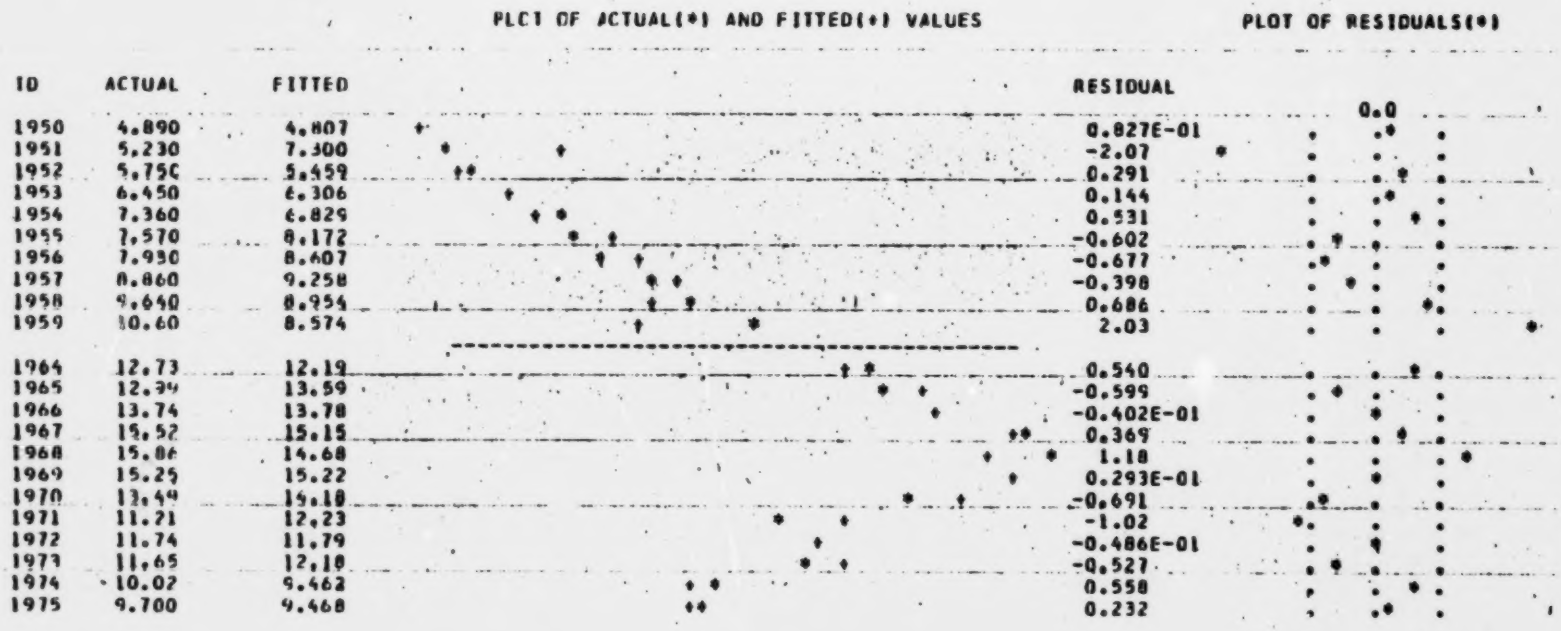
F-statistic (2,22) = 195.567

Durbin-Watson statistic = 1.4711

Standard error of the regression = 0.714097

Sum of squared residuals = 11.2186.

The Durbin-Watson statistic falls in the inconclusive region; however, the Hart-von Neumann statistic indicates positive autocorrelation is

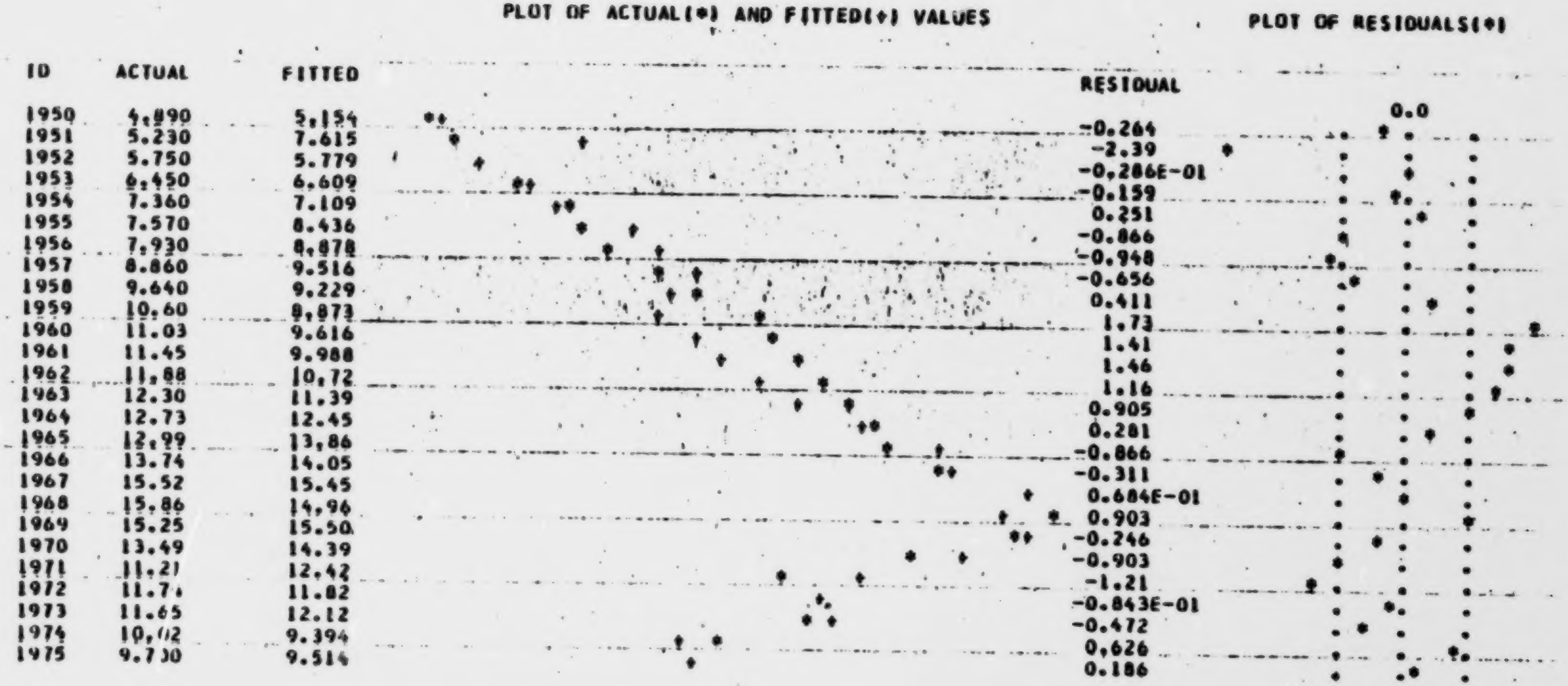


```
                        PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                              RESIDUAL
                                                                                          0.0
1950     4.890       4.807                                             0.827E-01
1951     5.230       7.300                                             -2.07
1952     5.750       5.459                                             0.291
1953     6.450       6.306                                             0.144
1954     7.360       6.829                                             0.531
1955     7.570       8.172                                             -0.602
1956     7.930       8.607                                             -0.677
1957     8.860       9.258                                             -0.398
1958     9.640       8.954                                             0.686
1959    10.60        8.574                                              2.03

1964    12.73       12.19                                              0.540
1965    12.99       13.59                                              -0.599
1966    13.74       13.78                                              -0.402E-01
1967    15.52       15.15                                              0.369
1968    15.86       14.68                                               1.18
1969    15.25       15.22                                              0.293E-01
1970    13.49       14.18                                              -0.691
1971    11.71       12.23                                              -1.02
1972    11.74       11.79                                              -0.486E-01
1973    11.65       12.18                                              -0.527
1974    10.02        9.462                                             0.558
1975     9.700       9.468                                             0.232
```

Figure 88. Plots for Productivity Model Excluding Seam Thickness Using Principal Components, 1950 Through 1959 and 1964 Through 1975: Eastern Kentucky (OLS)



```
                        PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
 ID      ACTUAL      FITTED
                                                  RESIDUAL
                                                                          0.0
1950     4.890       5.154                        -0.264
1951     5.230       7.615                         -2.39
1952     5.750       5.779                        -0.286E-01
1953     6.450       6.609                        -0.159
1954     7.360       7.109                         0.251
1955     7.570       8.436                        -0.866
1956     7.930       8.878                        -0.948
1957     8.860       9.516                        -0.656
1958     9.640       9.229                         0.411
1959    10.60        8.873                          1.73
1960    11.03        9.616                          1.41
1961    11.45        9.988                          1.46
1962    11.88       10.72                           1.16
1963    12.30       11.39                          0.905
1964    12.73       12.45                          0.281
1965    12.99       13.86                         -0.866
1966    13.74       14.05                         -0.311
1967    15.52       15.45                          0.684E-01
1968    15.86       14.96                          0.903
1969    15.25       15.50                         -0.246
1970    13.49       14.39                         -0.903
1971    11.21       12.42                          -1.21
1972    11.74       11.82                         -0.843E-01
1973    11.65       12.12                         -0.472
1974    10.02        9.394                         0.626
1975     9.700       9.514                         0.186
```

Figure 89. Plots for Productivity Model Excluding Seam Thickness Using Principal Components, 1950 Through 1975: Eastern Kentucky (OLS)

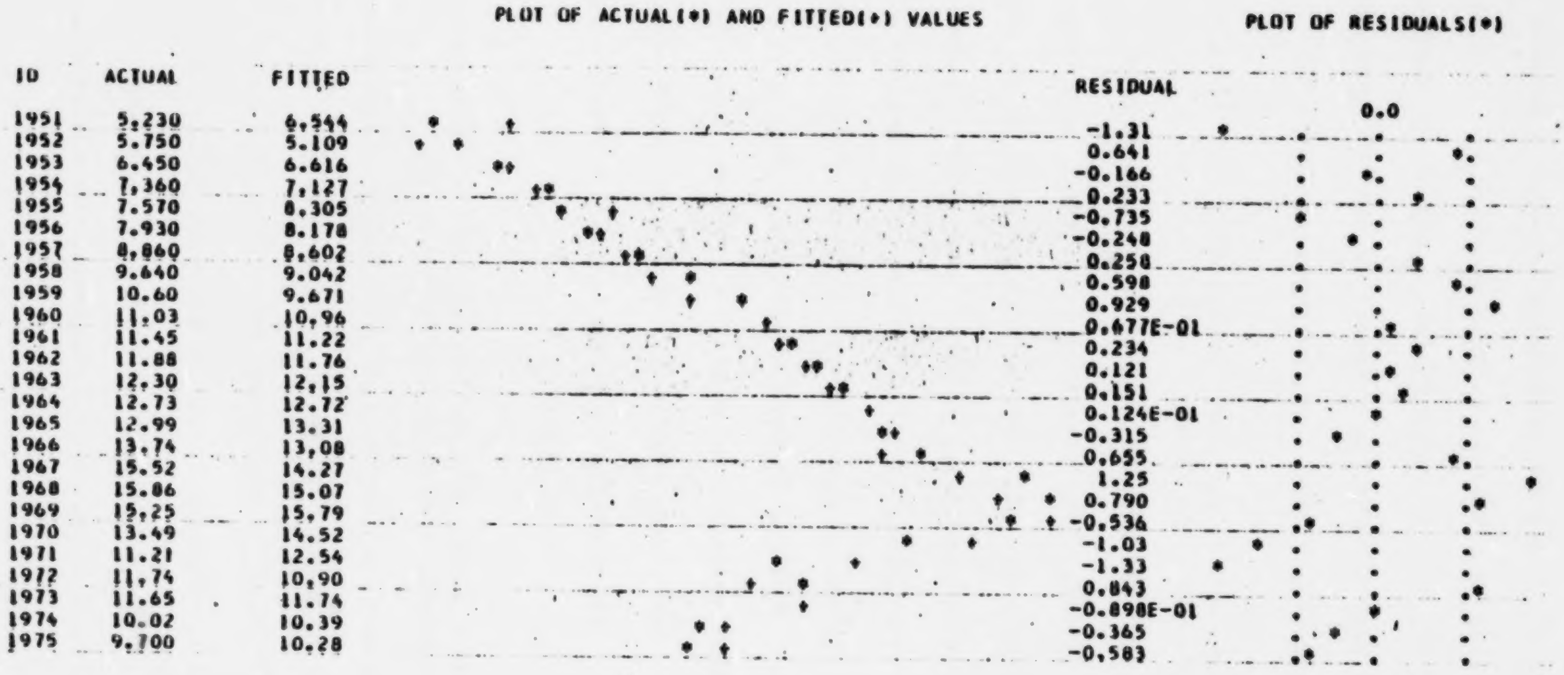
still present (95.0 percent confidence level). A greater percentage of the variation is explained in this equation (94.7) than in Equation 52E (91.0). The significance level of the coefficient of MACT is only 90.0 percent, as compared to that of Equation 52E which is 99.5. Appropriate plots are presented in Figure 90.

Results of Regressions for 1964 Through 1975 for Underground Rail-Connected and Truck Mines

Since data were available on all underground mines for only 12 years (1964 through 1975) (Table 37), the results of regressions of the model using these data are not considered to be as statistically valid as those derived using 22 or 26 observations. However, the results for rail-connected mines reflect larger average mine size than for all mines. A comparison of average production in Tables 33 and 37 reveals that the average mine size for rail mines only is up to ten times greater than that of all mines. Thus, it is useful to summarize regression results for all mines (Tables 38 and 39). These results are compared to those for rail-connected mines in the summary part of this section.

Results of Regressions of Data Through 1969 for Underground Rail-Connected Mines and Predictions of Productivity

In this section, derivations are presented of predictions of productivity levels that might have been attained if the Act had not been passed. First, a time trend of productivity before 1970 is used to predict possible levels of productivity in 1970 through 1975; second, estimates of the multivariate model are made with data before 1970, and actual values of the independent variables are combined



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                                   PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID      ACTUAL       FITTED                                           RESIDUAL
                                                                                          0.0
1951     5.230        6.544                                           -1.31
1952     5.750        5.109                                            0.641
1953     6.450        6.616                                           -0.166
1954     7.360        7.127                                            0.233
1955     7.570        8.305                                           -0.735
1956     7.930        8.178                                           -0.248
1957     8.860        8.602                                            0.258
1958     9.640        9.042                                            0.598
1959     10.60        9.671                                            0.929
1960     11.03        10.96                                            0.677E-01
1961     11.45        11.22                                            0.234
1962     11.88        11.76                                            0.121
1963     12.30        12.15                                            0.151
1964     12.73        12.72                                            0.124E-01
1965     12.99        13.31                                           -0.315
1966     13.74        13.08                                            0.655
1967     15.52        14.27                                            1.25
1968     15.86        15.07                                            0.790
1969     15.25        15.79                                           -0.536
1970     13.49        14.52                                           -1.03
1971     11.21        12.54                                           -1.33
1972     11.74        10.90                                            0.843
1973     11.65        11.74                                           -0.898E-01
1974     10.02        10.39                                           -0.365
1975     9.700        10.28                                           -0.583
```

Figure 90. Plots for Productivity Model Excluding Seam Thickness Using Principal Components, 1950 Through 1975: Eastern Kentucky (CORC)

Table 37

Data for Eastern Kentucky, Underground Rail-Connected and Truck Mines

Year	Productivity PRY (tons per man-day)	Average Production AP (tons)	Weighted-Average Seam Thickness ST (inches)	Percent of Coal Mined by Continuous Miners CM (percent)	Weighted-Average Days in Operation DO	Actual Price of Coal, 1975 Dollars PR_A (cents per million Btu)	Price of Coal Under the Assumption of No-Act, 1975 Dollars PR (cents per million Btu)	Number of Inspections Per Mine Under CMHSA MACT
1964	11.40	21208.8	42.25	12.55	198	28.7	28.7	0.0
1965	11.65	23671.0	42.12	14.02	205	27.7	27.7	0.0
1966	13.19	28153.4	43.15	12.16	202	27.0	27.0	0.0
1967	14.58	34328.4	43.16	15.71	209	27.7	27.7	0.0
1968	15.32	37832.9	43.72	17.37	209	27.0	27.0	0.0
1969	15.80	42230.7	44.24	19.15	215	27.1	27.1	0.0
1970	14.89	40996.9	44.61	17.88	208	30.8	24.1	5.15924
1971	12.92	39923.1	44.47	20.81	204	33.5	26.2	10.4678
1972	13.50	52306.6	44.85	22.62	214	35.4	27.7	29.2330
1973	13.86	67398.4	44.38	21.99	224	37.1	29.0	42.6833
1974	12.51	51802.1	44.61	30.92	212	54.4	42.6	52.0947
1975	12.12	44925.6	43.92	31.85	208	64.2	50.3	39.1479

Table 38

Results of Regressions Summary for Eastern Kentucky: Underground Rail-Connected and Truck Mines

(1964 Through 1975)

Equation	Constant	AP	ST	CM	DO	PR	MACT	PC	R^2	S	SSR	Auto-Correlation (Durbin-Watson Statistic)	F-Statistic
53(OLS)	-97.381	3.730	1.672 ##	-0.201	0.178 #	0.182	-0.093 ###		0.93	0.57	1.65	None (2.16)	$10.76_{(6,5)}$
54(OLS)	15.354						-0.126 #####	2.481 ****	0.85	0.62	3.46	None (1.89)	$25.36_{(2,9)}$

Significance Levels:
**** Significant at 99.0 percent confidence level (two-tail test)
# Significant at 90.0 percent confidence level (one-tail test)
Significant at 95.0 percent confidence level (one-tail test)
Significant at 97.5 percent confidence level (one-tail test)
Significant at 99.5 percent confidence level (one-tail test)

Table 39

Ninety-five Percent Confidence Intervals for Coefficients in Eastern Kentucky Regressions: Underground Rail-Connected and Truck Mines (1964 Through 1975)

Equation	AP		ST		CM		DO		PR		MACT		PC	
53(OLS)	-243.70	251.16	-0.23	3.58	-0.60	0.19	-0.07	0.43	-0.05	0.42	-0.18	-0.001		
54(OLS)											-0.17	-0.08	1.66	3.30

with this model to make predictions; and third, predictions are made based on the results of the model derived with data through 1975 by subtracting the negative influence of MACT on productivity.

The legislation could have indirect effects on productivity by affecting the other independent variables. To examine this possibility, the trend of each variable is reexamined. From Figures 72 and 74 it can be seen that both percent mined by continuous miners and weighted-average seam thickness have overall increasing trends with no change in 1969. Weighted-average days in operation (Figure 75) has a significant change in trend in 1969 (99.0 percent confidence level) from increasing to level or negative. This would more likely be due to reaching a "natural" limit or to increase in wildcat strikes than to the Mine Act. Average production (Figure 76) changes trend from positive to negative in 1969 (99.0 percent confidence level). As explained in the section on West Virginia, the mine size variable could have been affected by the Mine Act, but the expected effect would be to increase average mine size, not to decrease it. The effect of the Mine Act on the price of coal has been accounted for by subtracting out the estimated portion of the actual price increase that was due to the Mine Act. Thus, it is unlikely that the Mine Act had any large indirect effects on productivity.

Productivity shows a positive trend before 1968 and drops slightly in 1969. A simple regression of productivity with time (T) from 1 (1950) through 10 (1959) and 15 (1964) through 20 (1969) results in :

$$(55)\ PRY_t = \underset{(0.198)}{4.177} + \underset{(0.0167)^{****}}{0.5846T}$$

$R^2 = 0.9887$

F-statistic (1,14) = 1223.25

Durbin-Watson statistic = 1.5147

Standard error of the regression = 0.423

Sum of squared residuals = 2.503

Using estimates of productivity in 1960 through 1963, the results are:

$$(55E)\ PRY_t = \underset{(0.181)}{4.203} + \underset{(0.0151)^{****}}{0.5856T}$$

$R^2 = 0.9881$

F-statistic (1,18) = 1500.23

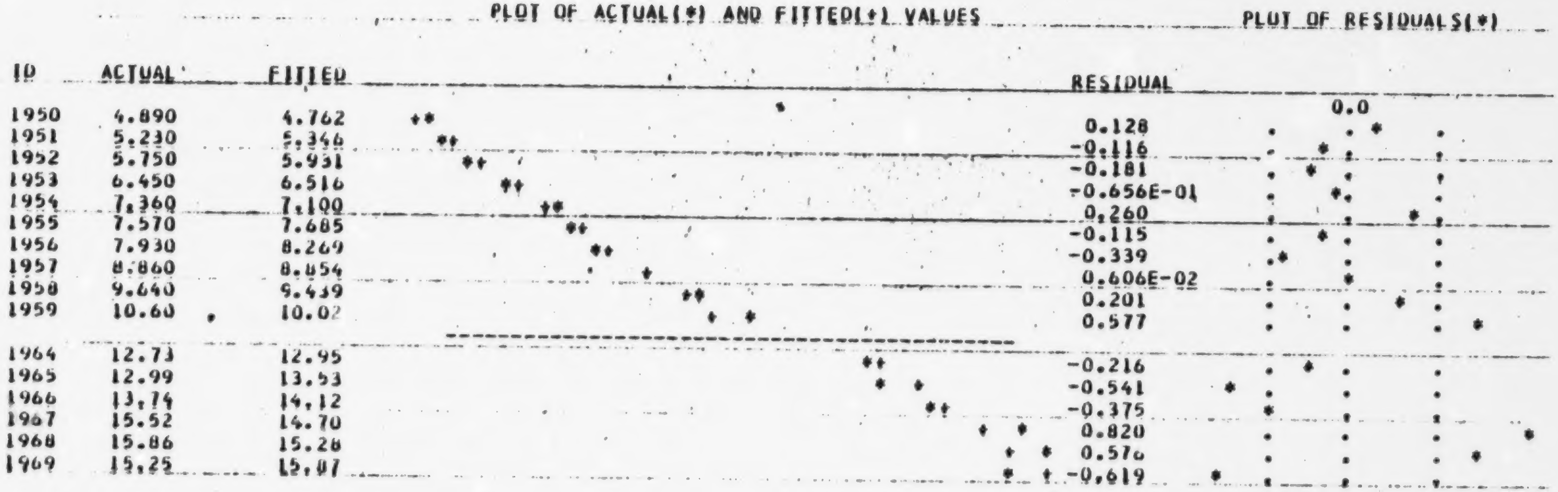
Durbin-Watson statistic = 1.4067

Standard error of the regression = 0.3899

Sum of squared residuals = 2.736

Both equations are significant at the 99.0 percent confidence level and explain almost 99.0 percent of the variance. Neither has autocorrelation. Appropriate plots are shown in Figures 91 and 92. As expected, the results of the two regressions are very similar.

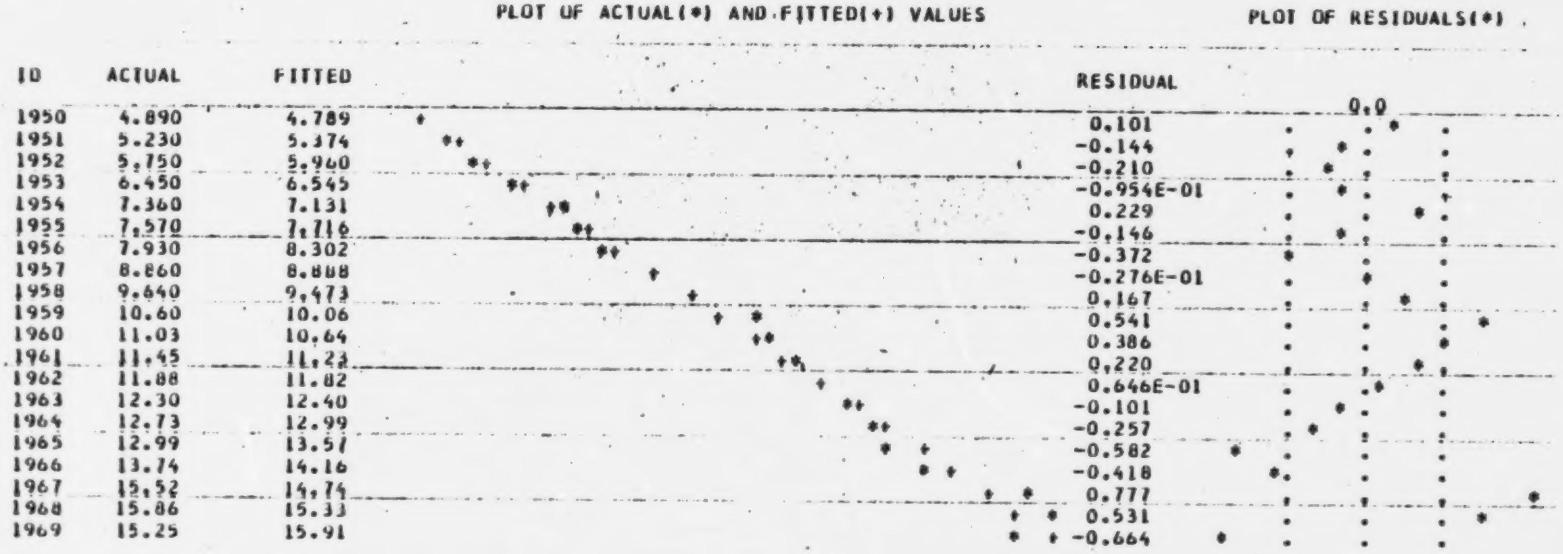
Both equations are used to predict productivity levels in 1970 through 1975, assuming that tons per man-day remains on this increasing trend. The predictions, shown in Table 40, are for increasing productivities that are significantly greater than actual values in all years.



```
                            PLOT OF ACTUAL(*) AND FITTED(+) VALUES                PLOT OF RESIDUALS(*)
ID     ACTUAL     FITTED                                    RESIDUAL
1950    4.890      4.762                                     0.128
1951    5.230      5.346                                    -0.116
1952    5.750      5.931                                    -0.181
1953    6.450      6.516                                    -0.656E-01
1954    7.360      7.100                                     0.260
1955    7.570      7.685                                    -0.115
1956    7.930      8.269                                    -0.339
1957    8.860      8.854                                     0.606E-02
1958    9.640      9.439                                     0.201
1959   10.60      10.02                                      0.577

1964   12.73      12.95                                     -0.216
1965   12.99      13.53                                     -0.541
1966   13.74      14.12                                     -0.375
1967   15.52      14.70                                      0.820
1968   15.86      15.28                                      0.576
1969   15.25      15.07                                     -0.619
```

Figure 91. Plots for Time Trend of Productivity, 1950 Through 1959 and 1964 Through 1969: Eastern Kentucky (OLS)



```
                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                              RESIDUAL
                                                                        0.0
1950     4.890       4.789                               0.101
1951     5.230       5.374                              -0.144
1952     5.750       5.960                              -0.210
1953     6.450       6.545                              -0.954E-01
1954     7.360       7.131                               0.229
1955     7.570       7.716                              -0.146
1956     7.930       8.302                              -0.372
1957     8.860       8.888                              -0.276E-01
1958     9.640       9.473                               0.167
1959    10.60       10.06                                0.541
1960    11.03       10.64                                0.386
1961    11.45       11.23                                0.220
1962    11.88       11.82                                0.646E-01
1963    12.30       12.40                               -0.101
1964    12.73       12.99                               -0.257
1965    12.99       13.57                               -0.582
1966    13.74       14.16                               -0.418
1967    15.52       14.74                                0.777
1968    15.86       15.33                                0.531
1969    15.25       15.91                               -0.664
```

Figure 92. Plots for Time Trend of Productivity, 1950 Through 1969: Eastern Kentucky (OLS)

Table 40

Comparison of Predicted Levels of Productivity Based on Time Trends and on Multiple Regressions With Actual Levels of Productivity in Eastern Kentucky for Underground Rail-Connected Mines

Year	Actual	Based on Simple Time Trend for 1950 Through 1959 and 1964 Through 1969 (OLS)	Based on Simple Time Trend for 1950 Through 1969 (OLS)	Based on AP, ST, CM, DO, and PR in Regression for 1950 Through 1969 and 1964 Through 1969 (OLS)	Based on AP, ST, CM, DO, and PR in Regression for 1950 Through 1969 (OLS)	Based on AP, CM, DO, and PR in Regression for 1950 Through 1959 and 1964 Through 1969 (OLS)	Based on AP, CM, DO, and PR in Regression for 1950 Through 1969 (OLS)
1970	13.49	16.45 (±1.02)	16.50 (±0.90)	15.30 (±1.02)	15.35 (±1.10)	15.51 (±1.23)	15.56 (±1.22)
1971	11.21	17.04 (±1.03)	17.09 (±0.91)	15.41 (±1.45)	15.27 (±1.55)	15.62 (±1.78)	15.49 (±1.73)
1972	11.74	17.62 (±1.05)	17.67 (±0.93)	15.59 (±1.75)	15.28 (±1.88)	15.35 (±2.15)	15.05 (±2.10)
1973	11.65	18.21 (±1.06)	18.26 (±0.94)	15.51 (±1.58)	15.21 (±1.67)	15.14 (±1.91)	14.82 (±1.84)
1974	10.02	18.79 (±1.08)	18.84 (±0.96)	16.04 (±3.91)	14.89 (±4.09)	13.89 (±4.28)	12.75 (±4.02)
1975	9.70	19.38 (±1.10)	19.43 (±0.97)	14.56 (±4.67)	13.09 (±4.83)	12.09 (±5.17)	10.62 (±4.77)

A regression was run for 1950 through 1959 and 1964 through 1969 with productivity as a function of average production, weighted-average seam thickness, percent mined by continuous miners, and weighted-average days in operation. The results are:

$$(56)\ PRY_t = -\ 8.88698 + 15.8066\ AP_t + 0.516119\ ST_t$$
$$(11.2066)\quad (4.75934)\#\#\#\#\#(0.193386)\#\#\#$$

$$+\ 0.259981\ CM_t - 0.0304798\ DO_t\ -\ 0.155190\ PR_t$$
$$(0.0543903)\#\#\#\#\#(0.0138377)^{*}\quad (0.0538505)\#\#\#\#$$

$R^2 = 0.9937$

F-statistic (5,10) = 317.841

Durbin-Watson statistic = 2.1590

Standard error of the regression = 0.371932

Sum of squared residuals = 1.38333.

Using estimated data in 1960 through 1963, the results are:

$$(56E)\ PRY_t = -6.32941 + 16.9691\ AP_t + 0.501802\ ST_t$$
$$(12.5617)\quad (5.30695)\#\#\#\#\#\ (0.218422)\#\#\#$$

$$+\ 0.221915\ CM_t - 0.0326221\ DO_t$$
$$(0.0590019)\#\#\#\#\#\ (0.0130997)^{**}$$

$$-\ 0.191746\ PR_t$$
$$(0.0566890)\#\#\#\#\#$$

$R^2 = 0.9892$

F-statistic (5,14) = 256.738

Durbin-Watson statistic = 1.7237

Standard error of the regression = 0.421680

Sum of squared residuals = 2.48940.

For both of these equations, the coefficients of AP and CM are significant at the 99.5 percent confidence level, and the coefficients of ST are significant at the 97.5 percent confidence level. Weighted-average days in operation and price also have significant coefficients in both equations. All coefficients have expected signs except DO. The equations are significant at the 99.0 percent confidence level, and approximately 99.0 percent of the variation is explained. Neither equation has autocorrelation. The pairwise correlation matrix (Table 41) for Equation 56 shows the highest correlations between AP and CM (0.91), PR and ST (-0.91), CM and PR (-0.91), and DO and PR (-0.89). The pairwise correlation matrix (Table 42) for Equation 56E shows the highest correlations between the same variable pairs, as expected. Appropriate plots are given in Figures 93 and 94 for Equations 56 and 56E, respectively. The residuals plots show no evidence for the presence of heteroskedasticity. The results of the two equations are similar.

Table 41

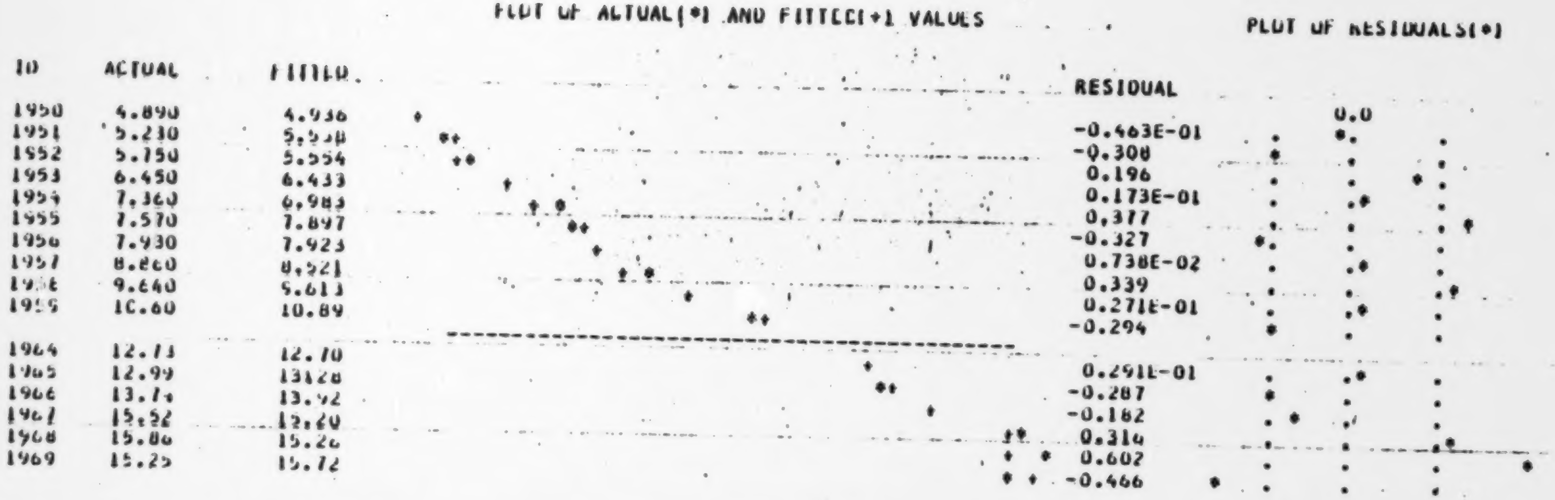
Pairwise Correlation Matrix for AP, ST, CM, DO, and PR: Eastern Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1969)

	AP	ST	CM	DO	PR
AP	1.0000	0.61544	0.91466	0.78468	-0.78934
ST	0.61544	1.0001	0.76743	0.82331	-0.91058
CM	0.91460	0.76743	1.0000	0.84203	-0.91167
DO	0.78468	0.82331	0.84203	1.0000	-0.88902
PR	-0.78934	-0.91058	-0.91167	-0.88902	1.0000

Table 42

Pairwise Correlation Matrix for AP, ST, CM, DO, and PR: Eastern Kentucky Underground Rail-Connected Mines (1950 Through 1969)

	AP	ST	CM	DO	PR
AP	1.0000	0.59206	0.90909	0.77605	-0.76368
ST	0.59206	1.0001	0.75690	0.76677	-0.91537
CM	0.90909	0.75690	1.0000	0.81697	-0.89885
DO	0.77605	0.76677	0.81697	1.0000	-0.83395
PR	-0.76368	-0.91537	-0.89885	-0.83395	1.0000

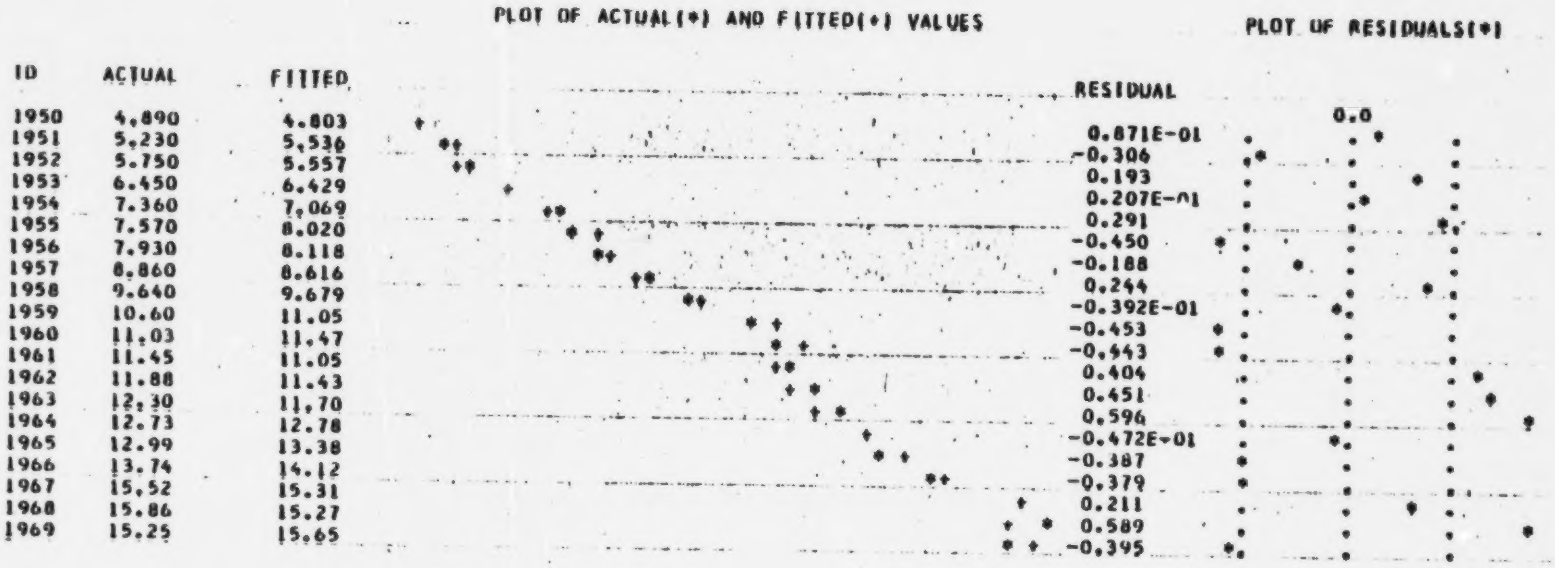


```
ID      ACTUAL      FITTED      RESIDUAL

1950    4.890       4.936       -0.463E-01
1951    5.230       5.538       -0.308
1952    5.750       5.554        0.196
1953    6.450       6.433        0.173E-01
1954    7.360       6.983        0.377
1955    7.570       7.897       -0.327
1956    7.930       7.923        0.738E-02
1957    8.860       8.521        0.339
1958    9.640       9.613        0.271E-01
1959    10.60       10.89       -0.294

1964    12.73       12.70        0.291E-01
1965    12.99       13.28       -0.287
1966    13.74       13.92       -0.182
1967    15.52       15.20        0.314
1968    15.86       15.26        0.602
1969    15.25       15.72       -0.466
```

Figure 93. Plots for Productivity Model, 1950 Through 1959 and 1964 Through 1969: Eastern Kentucky (OLS)



```
                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES            PLOT OF RESIDUALS(*)
ID      ACTUAL      FITTED                                          RESIDUAL
                                                                                 0.0
1950    4.890       4.803                                           0.871E-01
1951    5.230       5.536                                          -0.306
1952    5.750       5.557                                           0.193
1953    6.450       6.429                                           0.207E-01
1954    7.360       7.069                                           0.291
1955    7.570       8.020                                          -0.450
1956    7.930       8.118                                          -0.188
1957    8.860       8.616                                           0.244
1958    9.640       9.679                                          -0.392E-01
1959    10.60       11.05                                          -0.453
1960    11.03       11.47                                          -0.443
1961    11.45       11.05                                           0.404
1962    11.88       11.43                                           0.451
1963    12.30       11.70                                           0.596
1964    12.73       12.78                                          -0.472E-01
1965    12.99       13.38                                          -0.387
1966    13.74       14.12                                          -0.379
1967    15.52       15.31                                           0.211
1968    15.86       15.27                                           0.589
1969    15.25       15.65                                          -0.395
```

Figure 94. Plots for Productivity Model, 1950 Through 1969: Eastern Kentucky (OLS)

Eliminating ST from the regression, the results using data from 1950 through 1959 and 1964 through 1969 are:

(57) $PRY_t = 19.3085 + 12.5405\ AP_t$

$(4.66424)\ (5.73829)\#\#$

$+ 0.249224\ CM_t\ 0.0225885\ DO_t - 0.252117\ PR_t$

$(0.0676730)\#\#\#\#\#(0.0168658)\ (0.0496070)\#\#\#\#\#$

$R^2 = 0.9893$

F-statistic (4,11) = 254.090

Durbin-Watson statistic = 1.7186

Standard error of the regression = 0.464038

Sum of squared residuals = 2.36864.

Using estimated data in 1960 through 1963, the results are:

(57E) $PRY_t = 21.4950 + 13.8270\ AP_t + 0.211194\ CM_t$

$(3.77917)\ (5.81311)\#\#\#\ \ (0.066679)\#\#\#\#\#$

$- 0.0264094\ DO_t - 0.288914\ PR_t$

$(0.0145309)^*\ \ \ (0.0427918)\#\#\#\#\#$

$R^2 = 0.9851$

F-statistic (4,15) = 248.679

Durbin-Watson statistic = 1.6015

Standard error of the regression = 0.478046

Sum of squared residuals = 3.42791.

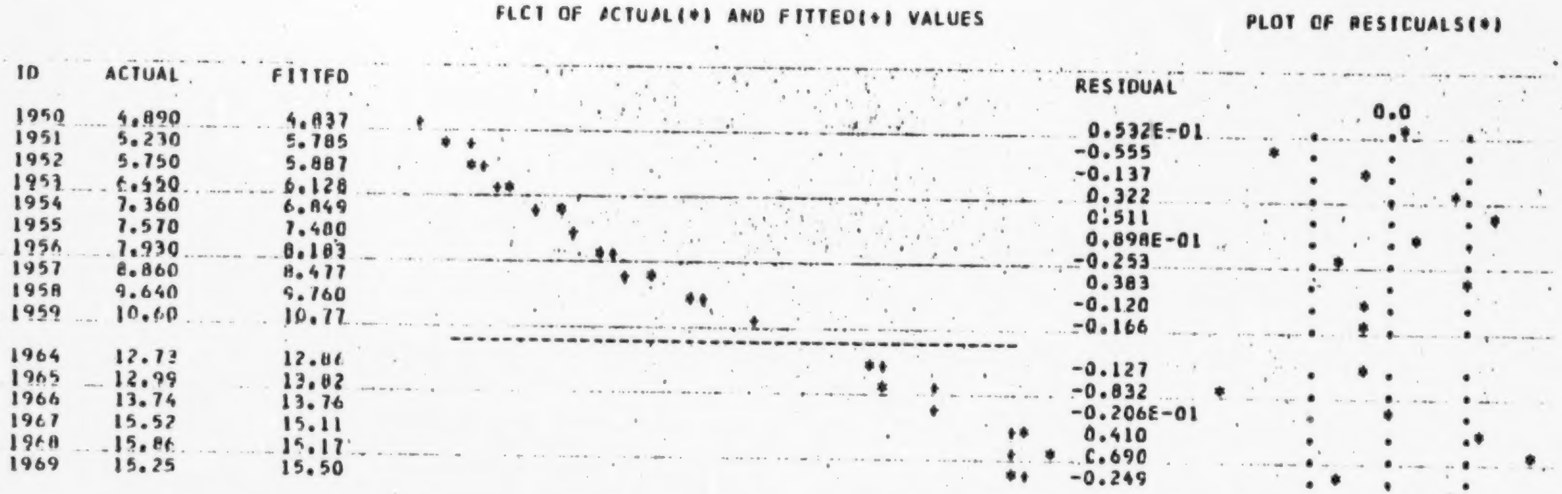
Again, the results of the two equations are similar. Coefficients of CM and PR are significant in both equations at the 99.5 percent confidence level; those of AP are significant in both equations also. The coefficients of DO are the only ones with unexpected signs; only in Equation 57E is it significant at a 90.0 percent confidence level. Almost 99.0 percent of the variance is explained, and both equations are significant at the 99.0 percent confidence level. Neither regression has autocorrelation, according to the Hart-von Neumann statistic; the Durbin-Watson test is inconclusive. Appropriate plots for Equations 57 and 57E are shown in Figures 95 and 96 , respectively. The residuals plots show no evidence for the presence of heteroskedasticity.

A comparison of Equation 56 with 57 and 56E with 57E indicates that ST is significant in explaining productivity, since the respective F-values are $7.12_{(1,10)}$ and $5.28_{(1,14)}$ (95.0 percent confidence level).

Predictions based on these four equations are shown in Table 40. The predictions in 1970 through 1973 are all significantly greater than actual values. In 1974, the predictions from equations with ST are significantly greater than actual values. In 1975, only the equation with ST using no estimated data predicts a value significantly greater than actual. All of the predictions are for approximately level values of productivities for 1970 through 1973 with decreasing productivities in 1974 and 1975.

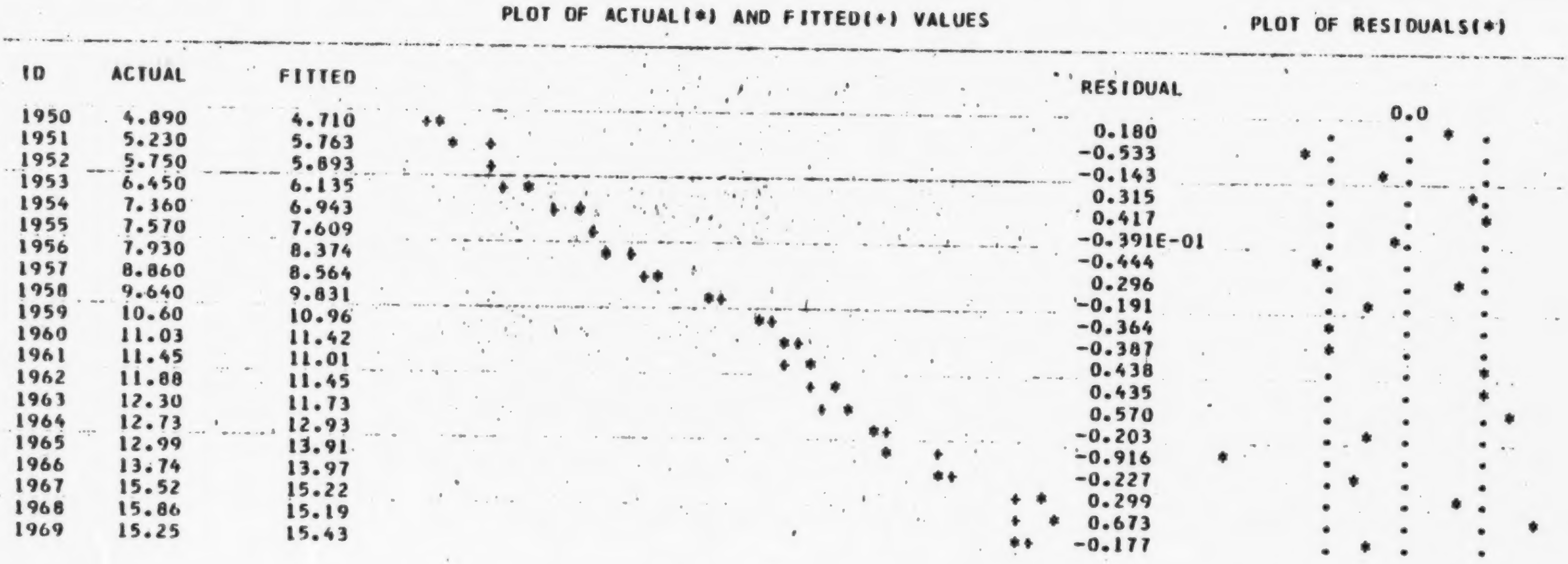
Data for all underground mines cannot be used to predict productivities in 1970 through 1975 by this method, since there are only six observations (1964 through 1969) and five independent variables plus a constant. This leaves zero degrees of freedom.

The results of the models using data through 1975 were used to make predictions of productivity without the Mine Act. This was done by adding the amount of productivity lost due to the Mine Act to the prediction of productivity for each year. For rail mines, these predictions, shown in Table 43, are for productivities that are greater than actual productivities and that decline overall through time. For example, in 1975 the



ID	ACTUAL	FITTED	RESIDUAL
1950	4.890	4.837	0.532E-01
1951	5.230	5.785	-0.555
1952	5.750	5.887	-0.137
1953	6.450	6.128	0.322
1954	7.360	6.849	0.511
1955	7.570	7.480	0.898E-01
1956	7.930	8.183	-0.253
1957	8.860	8.477	0.383
1958	9.640	9.760	-0.120
1959	10.60	10.77	-0.166
1964	12.73	12.86	-0.127
1965	12.99	13.82	-0.832
1966	13.74	13.76	-0.206E-01
1967	15.52	15.11	0.410
1968	15.86	15.17	0.690
1969	15.25	15.50	-0.249

Figure 95. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1959 and 1964 Through 1969: Eastern Kentucky (OLS)



```
                        PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)
ID     ACTUAL     FITTED                                   RESIDUAL
                                                                              0.0
1950   4.890      4.710                                     0.180
1951   5.230      5.763                                    -0.533
1952   5.750      5.893                                    -0.143
1953   6.450      6.135                                     0.315
1954   7.360      6.943                                     0.417
1955   7.570      7.609                                    -0.391E-01
1956   7.930      8.374                                    -0.444
1957   8.860      8.564                                     0.296
1958   9.640      9.831                                    -0.191
1959   10.60      10.96                                    -0.364
1960   11.03      11.42                                    -0.387
1961   11.45      11.01                                     0.438
1962   11.88      11.45                                     0.435
1963   12.30      11.73                                     0.570
1964   12.73      12.93                                    -0.203
1965   12.99      13.91                                    -0.916
1966   13.74      13.97                                    -0.227
1967   15.52      15.22                                     0.299
1968   15.86      15.19                                     0.673
1969   15.25      15.43                                    -0.177
```

Figure 96. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1969: Eastern Kentucky (OLS)

Table 43

Effect of MACT and PR on Productivity in Underground Rail-Connected Mines: Eastern Kentucky*

Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT	Mean		(2) Value of MACT	Tons Per Man-Day (3) Reduction in Productivity Caused by MACT -((1) x (2)) Low	Mean	High	(4) Prediction of Productivity from Model (95.0 percent confidence level)	(5) Prediction of Productivity Without MACT (4) + (3) Low	Mean	High	(6) Actual Productivity
1969	-0.110	-0.067	-0.024	0				15.48				15.25
1970				5.15924	0.12	0.35	0.57	14.07	14.19	14.42	14.64	13.49
1971				10.4678	0.25	0.70	1.15	12.71	12.96	13.41	13.86	11.21
1972				29.2330	0.70	1.96	3.22	11.61	12.31	13.57	14.83	11.74
1973				42.6833	1.02	2.86	4.70	11.52	12.54	14.38	16.22	11.65
1974				52.0947	1.25	3.49	5.73	9.93	11.18	13.42	15.66	10.02
1975				39.1479	0.94	2.62	4.31	9.59	10.53	12.21	13.90	9.70

Year	(7) 95.0 Percent Confidence Interval for Coefficient of PR	Mean		Cents Per Million Btu (8) Value of PR	(9) Change in PR From 1969	Tons Per Man-Day (10) Reduction in Productivity Caused by Change in PR -((7) x (9)) Low	Mean	High
1969	-0.034	-0.104	-0.174	27.1				
1970				24.1	-3.0	-0.102	-0.312	-0.522
1971				26.2	-0.9	-0.031	-0.094	-0.157
1972				27.7	0.6	0.020	0.062	0.104
1973				29.0	1.9	0.065	0.198	0.331
1974				42.6	15.5	0.527	1.612	2.697
1975				50.3	23.2	0.789	2.413	4.037

---

*Using results of Equation 48.

prediction is 12.21 tons per man-day as compared to an actual productivity of 9.70. For comparison the loss in productivity due to the change in price is also shown in Table 43. These results show that the Mine Act had a greater effect on productivity than did the rising price of coal. In Table 44, these predictions are reported for all mines. The Mine Act has a greater negative effect on the productivity in all mines (thus, in truck mines) than on rail-connected mines, since the coefficient of MACT has a greater absolute value for all mines (0.093) than for rail mines (0.067). In terms of percentage losses in productivity due to MACT, there are larger losses in every year for all mines, also (Table 45). For example, in 1975 the results indicate that productivity was down due to the Mine Act by around 22.6 percent for all mines and by around 21.5 percent for rail mines only.

Summary

Some of the results of the regressions are summarized in Tables 46, 47, 48, and 49. The relationships of the independent variables to productivity in the model using data on rail-connected mines for 1950 through 1959 and 1964 through 1975 may be summarized as follows:

(1) average production is positively related and significant;

(2) weighted-average seam thickness is positively related and significant;

(3) percent mined by continuous miners is positively related and significant;

(4) weighted-average days in operation is negative and is not significant;

(5) price is negatively related and significant; and

Table 44

Effect of MACT on Productivity in Underground Rail-Connected and Truck Mines: Eastern Kentucky*

Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	Tons Per Man-Day (3) Reduction in Productivity Caused by MACT			(4) Prediction of Productivity from Model (95.0 percent confidence level)	(5) Prediction of Productivity Without MACT			(6) Actual Productivity
		Mean			Low	Mean	High		Low	Mean	High	
					-((1) x (2))				(4) + (3)			
1969	0	-0.093	-0.1.84	0				16.20				15.80
1970				5.15924	0	0.52	1.03	14.80	14.80	15.32	15.83	14.89
1971				10.4678	0	0.97	1.93	13.15	13.15	14.12	15.08	12.92
1972				29.2330	0	2.72	5.38	13.79	13.79	16.51	19.17	13.50
1973				42.6833	0	3.97	7.85	13.96	13.96	17.93	21.81	13.86
1974				52.0947	0	4.84	9.59	11.96	11.96	16.80	21.55	12.51
1975				39.1479	0	3.64	7.20	12.47	12.47	16.11	19.67	12.12

---

[*] Using results of Equation 53. PR does not have a negative effect on productivity in this case, since the coefficient is positive.

Table 45

Percentage Losses in Productivity Due to the Mine Act in Eastern Kentucky

Year	Rail Mines Using Predictions of Regression 48 (Data Through 1975) (percentage loss)	All Mines Using Predictions of Regression 53 (Data Through 1975 (percentage loss)
1970	2.4	3.4
1971	5.2	6.9
1972	14.4	16.5
1973	19.9	22.1
1974	26.0	28.8
1975	21.5	22.6
Average Per Year	14.9	16.7

Table 46

Results of Regressions Summary for Eastern Kentucky: Underground Rail Mines (1950 Through 1959 and 1964 Through 1975; 1950 Through 1975‡)

Equation	Constant	AP	ST	CM	DO	PK	MACT	PC	R^2	S	SSR	Autocorrelation (Durbin-Watson Statistic)	F-Statistic
48(OLS)	-30.112	30.780 #####	0.806 #####	0.106 ###	-0.017	-0.104 #####	-0.067 #####		0.97	0.64	6.20	None (2.10)	$93.34_{(6,15)}$
48E(OLS)	-34.952	31.640 #####	0.949 #####	0.095 ###	-0.027	-0.108 #####	-0.067 #####		0.97	0.64	7.80	None (1.71)	$95.98_{(6,19)}$
49(OLS)	10.979						-0.075 #####	3.570 ****	0.95	0.81	12.55	None (1.55)	$170.38_{(2,19)}$
49E(OLS)	11.125						-0.081 #####	3.298 ****	0.93	0.84	16.35	+(1.20)	$160.28_{(2,23)}$
49E-A(CORC)	11.704						-0.047 ##	1.566 ****	0.95	0.72	11.39	None (1.59)	$192.45_{(2,22)}$
50(OLS)	6.219	23.909 #####		0.168 #####	0.013	-0.148 #####	-0.066 ####		0.96	0.81	10.46	+(1.31)	$69.48_{(5,16)}$
50E(OLS)	10.659	23.620 #####		0.172 #####	-0.002	-0.176 #####	-0.065 ###		0.94	0.86	14.64	+(0.95)	$62.74_{(5,20)}$
51(CORC)	9.982	25.421 #####		0.156 #####	-0.010	-0.147 #####	-0.050 ##		0.96	0.77	8.36	None (1.84)	$64.72_{(5,14)}$
51E(CORC)	10.260	20.568 #####		0.060	-0.003	-0.092 #	-0.029		0.96	0.70	9.31	None (1.90)	$82.22_{(5,19)}$
52(OLS)	10.827						-0.056 #####	3.444 ****	0.94	0.88	14.59	None (1.51)	$145.31_{(2,19)}$
52E(OLS)	11.007						-0.063 #####	3.166 ****	0.91	0.98	22.11	+(1.00)	$115.53_{(2,23)}$
52E-A(CORC)	11.818						-0.038 #	1.380 ****	0.95	0.71	11.22	+(1.47)	$195.57_{(2,22)}$

‡Equations for 1950 through 1975, with estimated data for 1960 through 1963, are indicated with an "E".

Significance Levels:
**** Significant at 99.0 percent confidence level (two-tail test)
# Significant at 90.0 percent confidence level (one-tail test)
Significant at 95.0 percent confidence level (one-tail test)
Significant at 97.5 percent confidence level (one-tail test)
Significant at 98.0 percent confidence level (one-tail test)
Significant at 99.5 percent confidence level (one-tail test)

Table 47

Results of Regressions Summary for Eastern Kentucky: Underground Rail-Connected Mines
(1950 Through 1959 and 1964 Through 1969; 1950 Through 1969‡)

Equation	Constant	AP	ST	CM	DO	PR	R^2	S	SSR	Autocorrelation (Durbin-Watson Statistic)	F-Statistic
56(OLS)	-8.887	15.807 #####	0.516 ###	0.260 #####	-0.030 *	-0.155 ####	0.99	0.37	1.38	None(2.16)	$317.84_{(5,10)}$
56E(OLS)	-6.329	16.969 #####	0.502 ###	0.222 #####	-0.033 **	-0.192 #####	0.99	0.42	2.49	None(1.72)	$256.74_{(5,14)}$
57(OLS)	19.309	12.541 ##		0.249 #####	-0.023	-0.252 #####	0.99	0.46	2.37	None(1.72)	$254.09_{(4,11)}$
57E(OLS)	21.495	13.827 ###		0.211 #####	-0.026 *	-0.289 #####	0.99	0.48	3.43	None(1.60)	$248.68_{(4,15)}$

‡Equations for 1950 through 1969, with estimated data for 1960 through 1963, are indicated with an "E".

Significance Levels:
* Significant at 90.0 percent confidence level (two-tail test)
** Significant at 95.0 percent confidence level (two-tail test)
Significant at 95.0 percent confidence level (one-tail test)
Significant at 97.5 percent confidence level (one-tail test)
Significant at 98.0 percent confidence level (one-tail test)
Significant at 99.5 percent confidence level (one-tail test)

Table 48

Ninety-five Percent Confidence Intervals for Coefficients in Eastern Kentucky Regressions: Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1975; 1950 Through 1975‡)

Equation	AP		ST		CM		DO		PR		MACT		PC	
48(OLS)	18.14	43.42	0.27	1.34	0.01	0.20	-0.06	0.03	-0.17	-0.03	-0.11	-0.02		
48E(OLS)	19.43	43.85	0.46	1.44	0.04	0.18	-0.07	0.01	-0.18	-0.04	-0.11	-0.02		
49(OLS)											-0.10	-0.05	[illegible]	3.98
49E(OLS)											-0.13	-0.03	2.92	3.68
49E-A(CORC)											-0.10	0.003	0.45	2.68
50(OLS)	9.15	38.67			0.06	0.27	-0.04	0.07	-0.23	-0.07	-0.12	-0.01		
50E(OLS)	8.32	38.92			0.06	0.28	-0.05	0.05	-0.25	-0.10	-0.12	-0.01		
51(OLS)	7.32	43.52			0.05	0.27	-0.06	0.05	-0.24	-0.05	-0.11	0.01		
51E(OLS)	5.52	35.62			-0.10	0.21	-0.04	0.04	-0.21	0.03	-0.08	0.03		
52(OLS)											-0.08	-0.03	3.02	3.87
52E(OLS)											-0.09	-0.03	2.74	3.60
52E-A(CORC)											-0.09	0.01	0.43	2.33

---

‡Equations for 1950 through 1975, with estimated data in 1960 through 1963, are indicated with an "E".

Table 49

Ninety-Five Percent Confidence Intervals for Coefficients in Eastern Kentucky Regressions: Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1969; 1950 Through 1969‡)

Equation	AP		ST		CM		DO		PR		T	
55(OLS)											0.55	0.62
55E(OLS)											0.55	0.61
56(OLS)	5.20	26.41	0.09	0.95	0.14	0.38	0.06	-0.00	-0.27	-0.04		
56E(OLS)	5.59	28.35	0.03	0.97	0.10	0.35	-0.06	-0.00	-0.31	-0.07		
57(OLS)	-0.09	25.17			0.10	0.40	-0.06	0.01	-0.36	-0.14		
57E(OLS)	1.44	26.21			0.07	0.35	-0.06	0.00	-0.38	-0.20		

‡Equations for 1950 through 1969, with estimated data in 1960 through 1963, are indicated with an "E".

(6) the Mine-Act variable is negatively related and significant. The regression analyses indicate that the effects of each independent variable on productivity in terms of approximate magnitude are:

(1) an increase in average production of 0.1 million tons increases productivity by 3.1 tons per man-day;

(2) an increase in weighted-average seam thickness of 1.0 inch increases productivity by 0.8 tons per man-day;

(3) an increase in percent of coal mined by continuous miners of 1.0 increases productivity by 0.1 tons per man-day;

(4) an increase in weighted-average days in operation of 10.0 decreases productivity by 1.7 tons per man-day;

(5) an increase in the price of coal by 1.0 cent per million Btu decreases productivity by 0.1 ton per man-day; and

(6) an increase severity of Act enforcement as approximated by a rise in inspection per mine by 10.0 decreases productivity by 0.7 tons per man-day.

Results of the regressions using estimated data in 1960 through 1964 are very similar to these.

The relationships of the independent variables to productivity in the model using data for all mines for 1964 through 1975 may be summarized as follows:

(1) average production is positively related and not significant;

(2) weighted-average seam thickness is positively related and significant

(3) percent mined by continuous miners is negatively related and not significant

(4) weighted-average days in operation is positive and significant;

(5) price is positively related and not significant; and

(6) the Mine-Act variable is negatively related and significant.

The regression analyses indicate that the effects of each independent variable on productivity in terms of approximate magnitude are:

(1) an increase in average production of 0.1 million tons increases productivity by 0.4 tons per man-day;

(2) an increase in weighted-average seam thickness of 1.0 inch decreases productivity by 1.7 tons per man-day;

(3) an increase in percent of coal mined by continuous miners of 1.0 decreases productivity by 0.2 tons per man-day;

(4) an increase in weighted-average days in operation of 10.0 increases productivity by 1.8 tons per man-day

(5) an increase in the price of coal by 1.0 cent per million Btu increases productivity by 0.2 tons per man-day; and

(6) an increase severity of CMHSA enforcement as represented by the number of inspections per mine by 10.0 decreases productivity by 0.9 tons per man-day.

The results of the model including seam thickness are expected to be best in this case because seams are relatively thin (around four feet), and a change of over ten percent (five inches) could theoretically make a more significant difference in productivity than five inches in seams that are already six or seven feet thick. Predictions of productivity based on the model including seam thickness using data from 1950 through 1959 and from model including seam thickness data from 1950 through 1959 and from 1964 through 1969 are significantly greater than actual values in all years

(Table 40). These results indicate that productivity was down in 1970 through 1975 by the following approximate percentages, respectively:

12.0, 27.0, 25.0, 25.0, 38.0, and 33.0

This is an average of around 27.0 percent per year.

Predictions of productivity without the Mine Act based on the model including seam thickness using data through 1975 are greater than actual values, but they are not as high as those derived from the model using data through 1969. These results indicate that productivity was down in rail-connected mines in 1970 through 1975 by the following percentages:

2.0, 5.0, 14.0, 20.0, 26.0, and 22.0.

This is an average of around 15.0 percent per year. In all mines, the corresponding percentage losses were:

3.0, 7.0, 17.0, 22.0, 29.0, and 23.0,

respectively, for an average of around 17.0 percent per year. Percentage losses in productivity due to the Mine Act are summarized in Table .

Western Kentucky

Data and Trends of Variables

The data used for western Kentucky are shown in Table 50. They are from the same sources as for eastern Kentucky. Data are missing in 1960 through 1963, as explained in the section on eastern Kentucky; these data are estimated in the same manner as for eastern Kentucky (Table 51).

The trend of productivity in rail-connected mines in western Kentucky for the years 1950 through 1959 and 1964 through 1975 is for overall increasing values through 1969 and decreasing values afterward (Figure 97). The overall percentage increase in productivity from 1950 through 1955 was 25.2. From 1955 through 1959, there was an overall decrease of 2.2 percent. From 1964 through 1969, there was an overall increase of 33.4 percent; from 1969 through 1975, the overall decrease in productivity was 48.9 percent. The level of productivity in 1975 was 13.69 -- similar to levels attained in 1953.

Using piecewise regression, it was found that the change in the trend of productivity with time since the 1969 Coal Mine Health and Safety Act took effect is statistically significant at the 99.0 percent confidence level. The results for this regression using a join point of 20(1969) are:

$$\begin{array}{l} (58)\ PRY_t = 10.097 + 0.7535\ X_1 - 2.878\ X_2\ (X_1 - 20) \\ \qquad\qquad\quad (0.912)\quad (0.0726)^{****}(0.329)^{****} \end{array}$$

Table 50

Data for Western Kentucky, Underground Rail-Connected Mines

Year	Productivity PRY (tons per man-day)	Average Production AP X10^6 (tons)	Weighted-Average Seam Thickness ST (inches)	Percent Mined by Continuous Miners CM (percent)	Weighted-Average Days in Operation DO	Actual Price of Coal, 1975 Dollars PR_A (cents per million Btu)	Price of Coal Under the Assumption of No-Act 1975 Dollars PR (cents per million Btu)	Number of Inspections Per Mine Under CMHSA MACT
1950	12.10	385626	65.27	0.17	214	49.6	49.6	0.0
1951	13.80	463531	63.92	0.30	216	45.3	45.3	0.0
1952	12.62	477669	64.54	0.52	216	44.7	44.7	0.0
1953	13.27	513480	63.45	0.90	211	43.4	43.4	0.0
1954	14.34	493366	63.46	1.19	201	39.8	39.8	0.0
1955	15.15	444245	65.77	1.79	192	37.5	37.5	0.0
1956	13.99	565517	64.01	2.22	223	36.2	36.2	0.0
1957	14.68	573587	64.59	4.18	203	36.0	36.0	0.0
1958	14.12	518779	63.60	6.95	196	34.8	34.8	0.0
1959	14.82	553902	61.15	7.19	203	33.2	33.2	0.0
1964	20.10	606312	61.83	12.55	228	28.7	28.7	0.0
1965	22.39	664886	61.21	14.02	222	27.7	27.7	0.0
1966	26.48	941649	60.41	12.16	227	27.0	27.0	0.0
1967	24.64	849049	60.16	15.71	241	27.7	27.7	0.0
1968	26.23	781166	60.27	17.37	238	27.0	27.0	0.0
1969	26.81	1010320	60.71	19.15	245	27.1	27.1	0.0
1970	23.01	894114	61.05	17.88	251	30.8	24.1	5.15924
1971	17.45	715912	60.73	20.81	219	33.5	26.2	10.4678
1972	15.48	727728	61.48	22.62	243	35.4	27.7	29.2330
1973	17.99	953948	61.37	21.99	254	37.1	29.0	42.6833
1974	15.34	940839	61.13	30.92	247	54.4	42.6	52.0947
1975	13.69	1039360	62.36	31.85	265	64.2	50.3	39.1479

Table 51

Estimated Data for Western Kentucky Underground Rail-Connected Mines

Year	Estimated Productivity PRY (tons per man-day)	Estimated Average Production AP X10^6 (tons)	Estimated Weighted-Average Seam Thickness ST (inches)	Actual Percent Mined by Continuous Miners CM (percent)	Estimated Weighted-Average Days in Operation DO	Actual Price of Coal, 1975 Dollars PR_A (cents per million Btu)
1960	15.88	564384	61.29	8.68	208	32.4
1961	16.93	574866	61.42	6.79	213	32.1
1962	17.99	585348	61.56	8.05	218	31.2
1963	19.04	595830	61.69	9.15	223	30.7

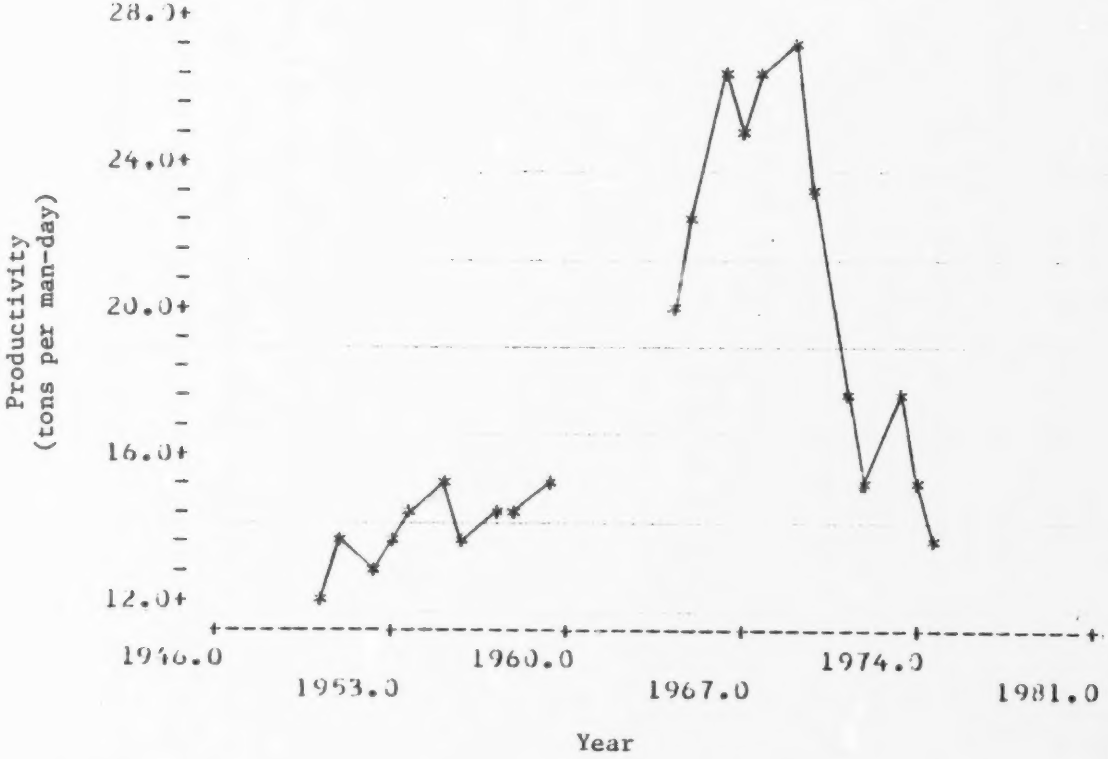


Figure 97. Trend of Productivity in Underground Coal Mines: Western Kentucky (1950 Through 1959 and 1964 Through 1975)

$R^2 = 0.855$

F-statistic (2,23) = 56.008

Standard error of the regression = 1.99

****Significant at the 99.0 percent confidence level.

Percent of coal mined by continuous miners (Figure 72) shows an overall increasing trend throughout the whole time period. Weighted-average seam thickness (Figure 98) shows two distinct populations, with seam thicknesses of around 64.5 inches from 1950 through 1958 and around 61.0 inches from 1959 through 1975. As in eastern Kentucky, the values from 1964 through 1975 are estimates based on information obtained from state mining personnel; however, these data were obtained from personnel in the western Kentucky District. The decrease in average seam thickness in 1959 and in 1964 through 1975 is assumed to be the actual behavior of this variable. This is because the value in 1959 is correct, having been calculated from actual data as from 1950 through 1958, and because the value in 1959 is similar to the values afterward. Thus, the values in 1964 through 1975 are assumed to be good estimates. Results are presented both with and without ST. The trend of ST is downward through 1967, then increasing afterward. A break in trend in this year is significant at the 99.0 percent confidence level. Weighted-average days in operation (Figure 99) and average production (Figure 100) both have generally increasing trends through time. The actual price of coal in Kentucky gradually declined before 1969, then increased afterward. A break in trend in 1969 is significant at the 99.0 percent confidence level. Under the assumption that there is no Coal Mine Health and Safety Act in 1970 through 1975, estimates indicate that the cost of coal in eastern Kentucky would have been around 22 percent less

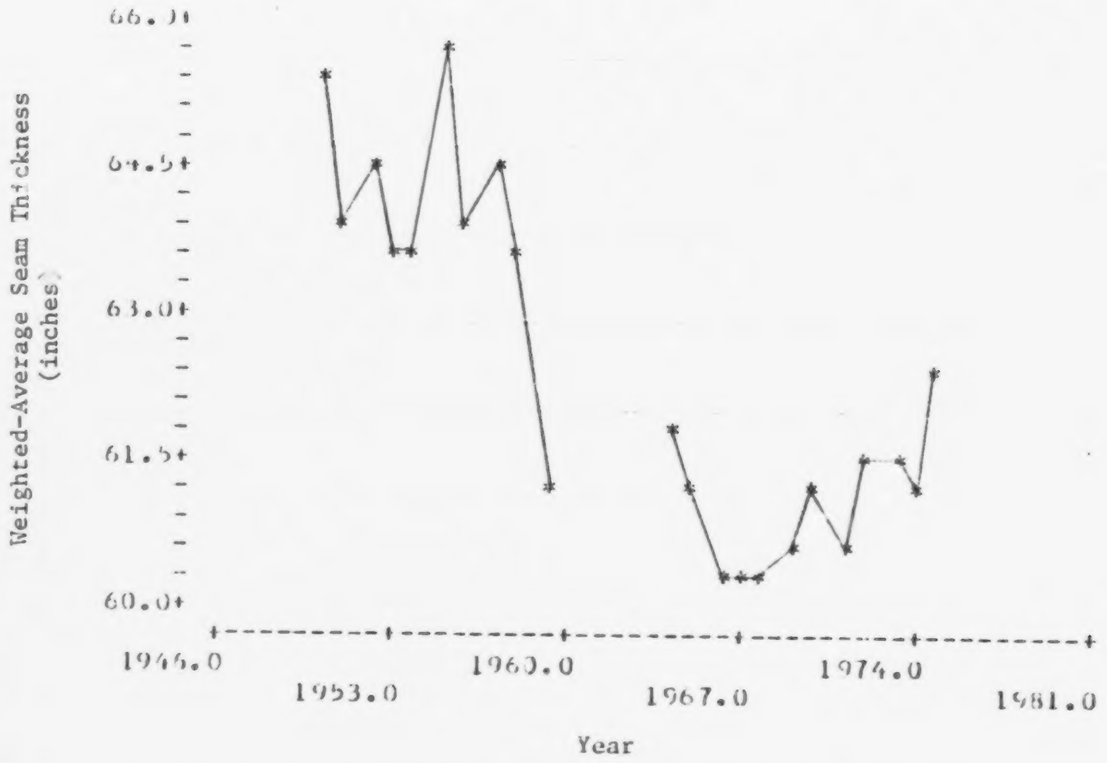


Figure 98. Trend of Weighted-Average Seam Thickness: Western Kentucky (1950 Through 1959 and 1964 Through 1975)

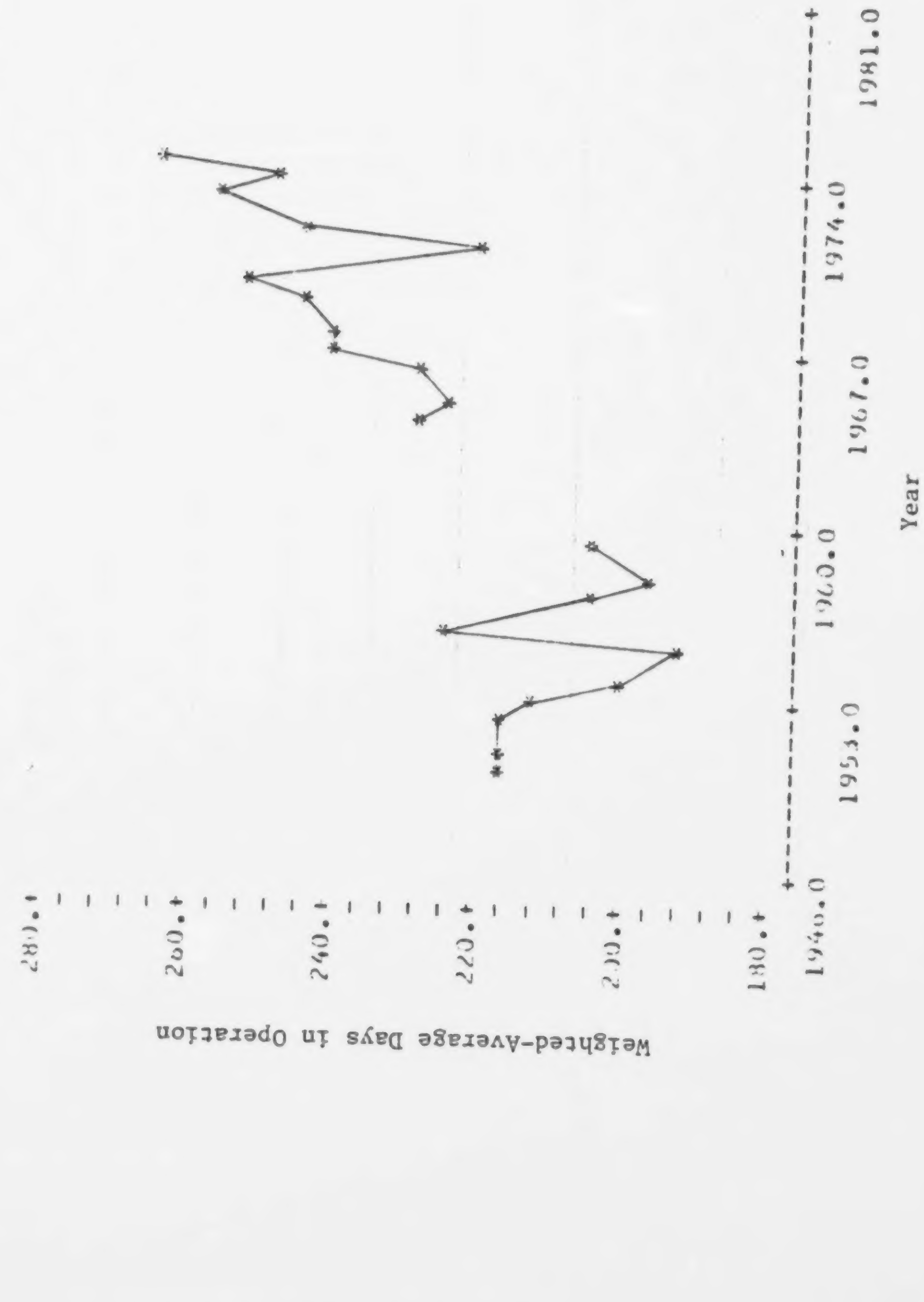


Figure 99. Trend of Weighted-Average Days in Operation: Western Kentucky (1950 Through 1959 and 1964 Through 1975)

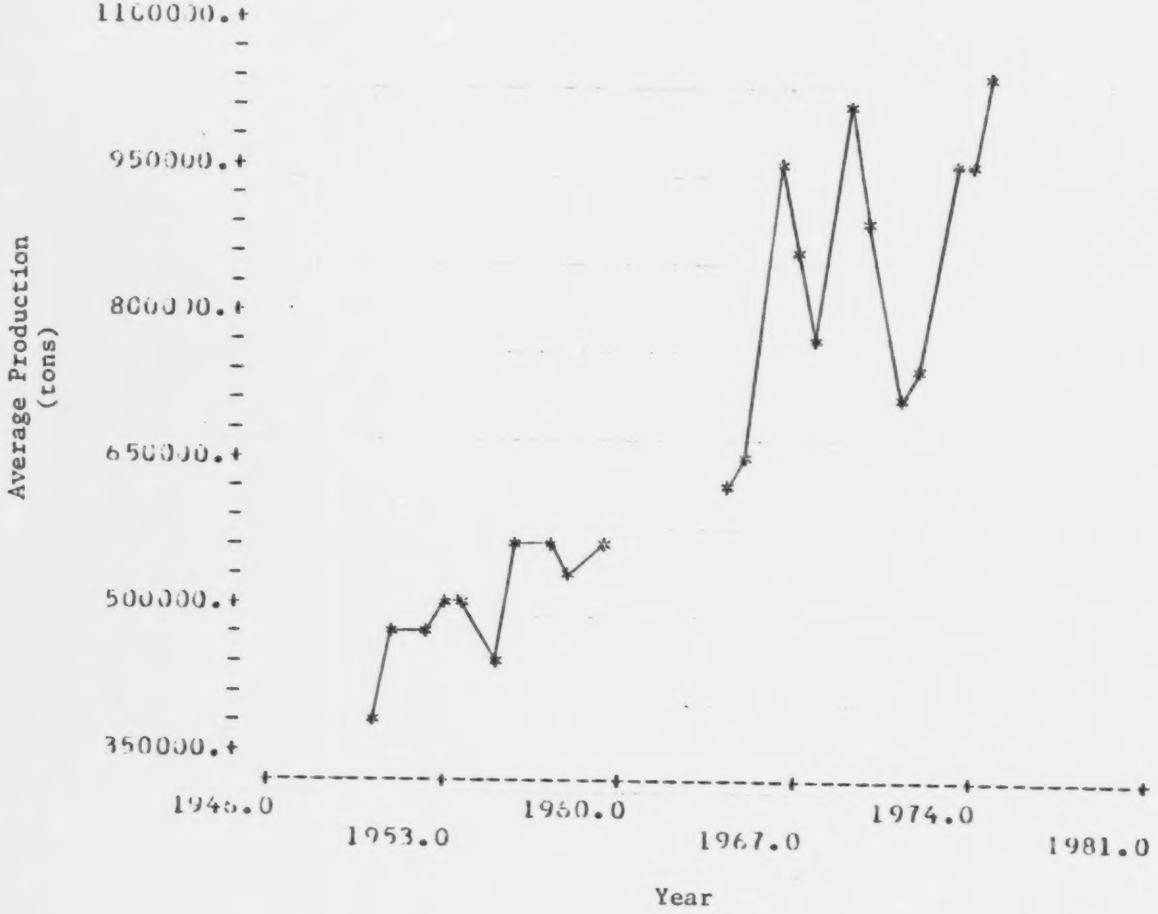


Figure 100. Trend of Average Production: Western Kentucky (1950 Through 1959 and 1964 Through 1975)

(Fettig, 1978; see Table 50). This was applied to the price trend, resulting in essentially the same trend, except that the increases are not so large (Figure 78).

Results of Regressions for Underground Rail-Connected Mines Using Data Through 1975

The results for the OLS regression of the model for the years 1950 through 1959 and 1964 through 1975 follow.

$$(59)\ PRY_t = \underset{(35.2818)}{36.8012} + \underset{(5.47595)\#\#\#\#\#}{15.0850}\ AP_t - \underset{(0.543813)}{0.463050}\ ST_t$$

$$- \underset{(0.138259)}{0.00801536}\ CM_t + \underset{(0.0453674)}{0.0310394}\ DO_t - \underset{(0.0839548)\#\#}{0.172596}\ PR_t$$

$$- \underset{(0.0555297)\#\#\#\#\#}{0.185528}\ MACT_t$$

$R^2 = 0.8901$

F-statistic (6,15) = 20.2522

Durbin-Watson statistic = 1.4976

Standard error of the regression = 1.94688

Sum of squared residuals = 56.8550.

Using estimated data in 1960 through 1963, the results are:

$$(59E)\ PRY_t = \underset{(28.2218)}{22.3750} + \underset{(4.82418)\#\#\#\#\#}{15.6013}\ AP_t - \underset{(0.441118)}{0.260795}\ ST_t$$

$$+ \underset{(0.124867)}{0.00245142}\ CM_t + \underset{(0.0404636)}{0.0386878}\ DO_t$$

$$- \underset{(0.0759934)\#\#\#}{0.184922}\ PR_t - \underset{(0.0503277)\#\#\#\#\#}{0.191108}\ MACT_t$$

$R^2 = 0.8845$

F-statistic (6,19) = 24.2466

Durbin-Watson statistic = 1.4644

Standard error of the regression = 1.78338

Sum of squared residuals = 60.4286.

In both equations, the coefficients of MACT are significant at the 99.5 percent confidence level. The coefficients of AP and PR are also significant in both equations. The coefficients of ST, CM, and DO are not significant. The coefficients of ST have unexpected signs in both equations; that of CM has an unexpected sign in Equation 59. Around 89.0 percent of the variation is explained, and the equations are significant at the 99.0 percent confidence level. According to the Hart-von Neumann statistics, Equation 59 has no autocorrelation; but 59E has positive autocorrelation (95.0 percent confidence level). The pairwise correlation matrices are shown in Tables 52 and 53. The highest pairwise correlations are between AP and CM, AP and DO, and DO and CM. Appropriate plots for Equations 59 and 59E are shown in Figures 101 and 102, respectively. The residuals plots show no evidence for the presence of heteroskedasticity.

The principal components method was used to correct for multicollinearity. The factor loadings and results of the OLS regression using data from 1950 through 1959 and 1964 through 1975 are:

Variable	Factor Loadings
AP	0.94565
ST	-0.89236
CM	0.91228
DO	0.86823
PR	-0.57367

Table 52

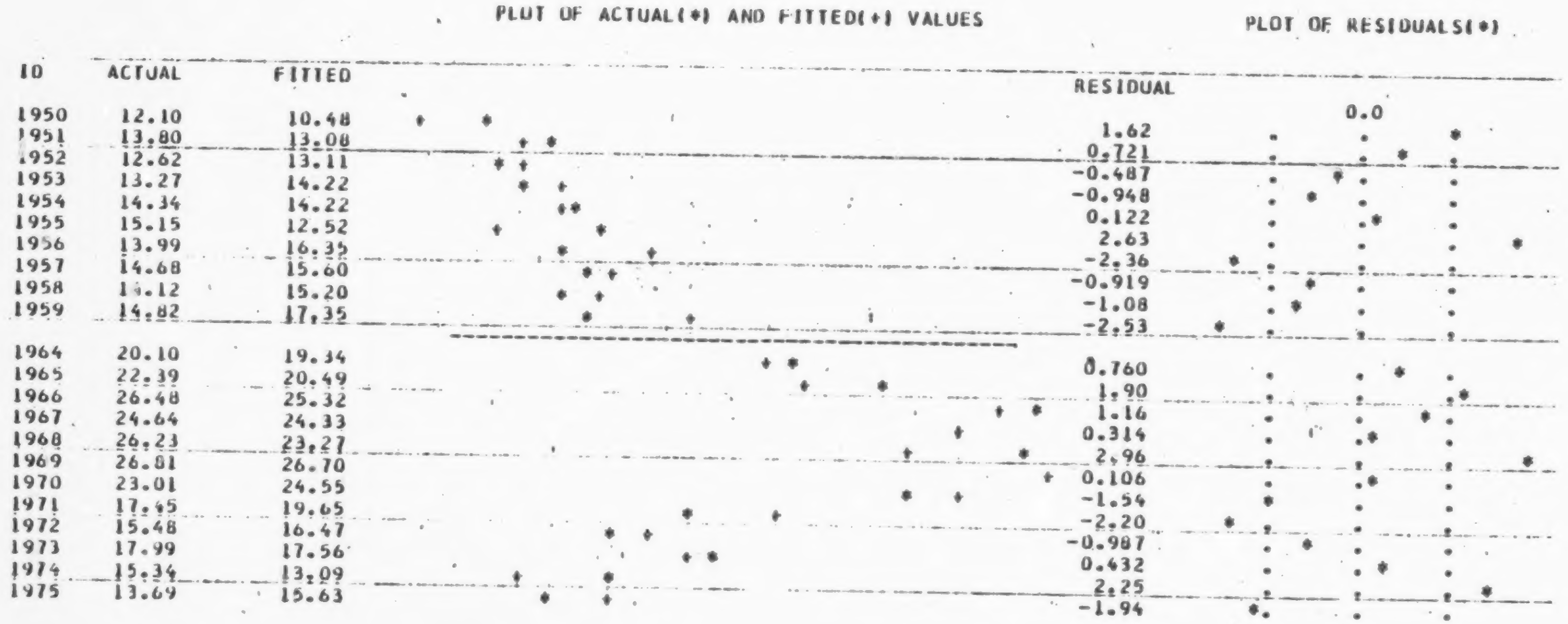
Pairwise Correlation Matrix for AP, ST, CM, DO, PR, and MACT: Western Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1975)

	AP	ST	CM	DO	PR	MACT
AP	1.0000	-0.76344	0.87531	0.86430	-0.40802	0.57624
ST	-0.76344	1.0002	-0.72105	-0.62774	0.69866	-0.26496
CM	0.87531	-0.72105	1.0000	0.83121	-0.32214	0.76192
DO	0.86430	-0.62774	0.83121	1.0000	-0.22088	0.64296
PR	-0.40802	0.69866	-0.32214	-0.22088	1.0000	0.14568
MACT	0.57624	-0.26496	0.76192	0.64296	0.14568	1.0000

Table 53

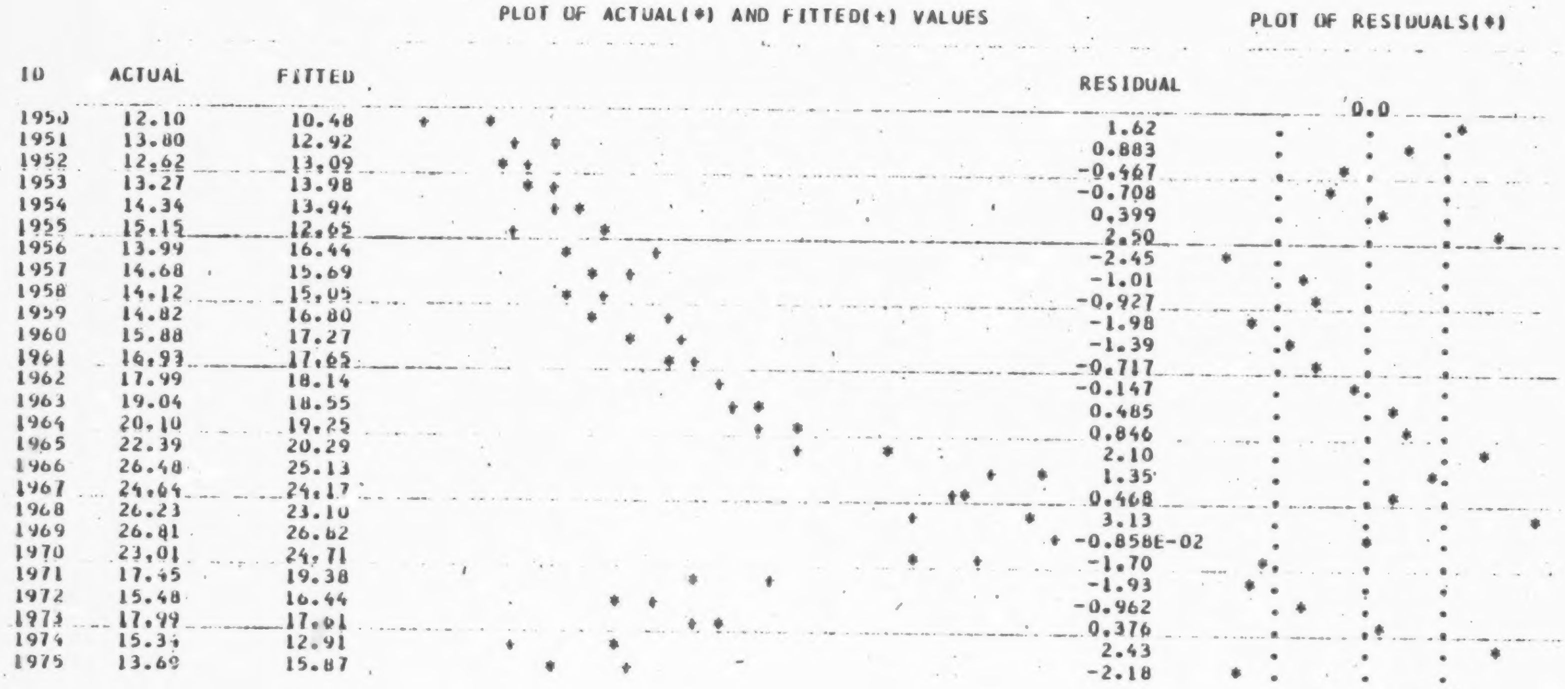
Pairwise Correlation Matrix for AP, ST, CM, DO, PR, and MACT: Western Kentucky Underground Rail-Connected Mines (1950 Through 1975)

	AP	ST	CM	DO	PR	MACT
AP	1.0000	-0.69048	0.87713	0.86601	-0.36411	0.59289
ST	-0.69048	1.0002	-0.66776	-0.55823	0.70496	-0.21538
CM	0.87713	-0.66776	1.0000	0.83044	-0.29225	0.76738
DO	0.86601	-0.55823	0.83044	1.0000	-0.18821	0.65159
PR	-0.36411	0.70496	-0.29225	-0.18821	1.0000	0.17116
MACT	0.59289	-0.21538	0.76738	0.65159	0.17116	1.0000



ID	ACTUAL	FITTED	RESIDUAL
1950	12.10	10.48	1.62
1951	13.80	13.08	0.721
1952	12.62	13.11	-0.487
1953	13.27	14.22	-0.948
1954	14.34	14.22	0.122
1955	15.15	12.52	2.63
1956	13.99	16.35	-2.36
1957	14.68	15.60	-0.919
1958	14.12	15.20	-1.08
1959	14.82	17.35	-2.53
1964	20.10	19.34	0.760
1965	22.39	20.49	1.90
1966	26.48	25.32	1.16
1967	24.64	24.33	0.314
1968	26.23	23.27	2.96
1969	26.81	26.70	0.106
1970	23.01	24.55	-1.54
1971	17.45	19.65	-2.20
1972	15.48	16.47	-0.987
1973	17.99	17.56	0.432
1974	15.34	13.09	2.25
1975	13.69	15.63	-1.94

Figure 101. Plots for Productivity Model, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (OLS)



```
                      PLOT OF ACTUAL(*) AND FITTED(+) VALUES                PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                       RESIDUAL
                                                                             0.0
1950    12.10       10.48                                          1.62
1951    13.80       12.92                                          0.883
1952    12.62       13.09                                         -0.467
1953    13.27       13.98                                         -0.708
1954    14.34       13.94                                          0.399
1955    15.15       12.65                                          2.50
1956    13.99       16.44                                         -2.45
1957    14.68       15.69                                         -1.01
1958    14.12       15.05                                         -0.927
1959    14.82       16.80                                         -1.98
1960    15.88       17.27                                         -1.39
1961    16.93       17.65                                         -0.717
1962    17.99       18.14                                         -0.147
1963    19.04       18.55                                          0.485
1964    20.10       19.25                                          0.846
1965    22.39       20.29                                          2.10
1966    26.48       25.13                                          1.35
1967    24.64       24.17                                          0.468
1968    26.23       23.10                                          3.13
1969    26.81       26.82                                         -0.858E-02
1970    23.01       24.71                                         -1.70
1971    17.45       19.38                                         -1.93
1972    15.48       16.44                                         -0.962
1973    17.99       17.61                                          0.376
1974    15.34       12.91                                          2.43
1975    13.69       15.87                                         -2.18
```

Figure 102. Plots for Productivity Model, 1950 Through 1975: Western Kentucky (OLS)

$$(60)\ PRY_t = 19.5453 + 5.39075\ PC_t - 0.232103\ MACT_t$$
$$(0.477531)(0.497198)^{****}(0.0304304)\#\#\#\#\#$$

$R^2 = 0.8652$

F-statistic (2,19) = 60.9687

Durbin-Watson statistic = 1.6384

Standard error of the regression = 1.91608

Sum of squared residuals = 69.7558.

The pairwise correlation matrix is:

	PC	MACT
PC	1.0000	0.54110
MACT	0.54110	1.0000

Using estimated data in 1960 through 1963, the results are:

Variable	Factor Loadings
AP	0.93855
ST	-0.85401
CM	0.91191
DO	0.86335
PR	-0.55110

$$(60E)\ PRY_t = 19.1974 + 4.96060\ PC_t - 0.228171\ MACT_t$$
$$(0.408913)(0.436660)^{****}(0.028595)\#\#\#\#\#$$

$R^2 = 0.8531$

F-statistic (2,23) = 66.7597

Durbin-Watson statistic = 1.4933

Standard error of the regression = 1.82817

Sum of squared residuals = 76.8707.

The correlation matrix is:

	PC	MACT
PC	1.0000	0.54668
MACT	0.54668	1.0000

The results of the two equations are similar, as expected. The principal component and the Mine-Act variables are significant at the 99.0 and 99.5 percent confidence levels in both equations. The coefficients of MACT have the expected signs. The percentage of variation explained is around 86.0, and both equations are significant at the 99.0 percent confidence levels. The correlations between the principal components and the Mine Act are not high. Equation 60 has no autocorrelation; Equation 60E has no autocorrelation according to the Hart-von Neumann statistic. Plots of actual and fitted values and residuals plots are shown in Figures 103 and 104 for Equations 60 and 60E, respectively. The residuals plots show no evidence of the presence of heteroskedasticity.

The results for the ordinary least squares regression of the model with seam thickness eliminated using data from 1950 through 1959 and 1964 through 1975 are:

$$
\begin{array}{llllll}
(61) & PRY_t = & 7.60164 & + 15.9607 + AP_t & + 0.0391541\ CM_t & \\
 & & (8.22547) & (5.33208)\#\#\#\#\# & (0.125583) & \\
 & & + 0.0333622\ DO_t & - 0.208724\ PR_t & - 0.200059\ MACT_t & \\
 & & (0.0448945) & (0.0718184)\#\#\#\# & (0.0523865)\#\#\#\#\# &
\end{array}
$$

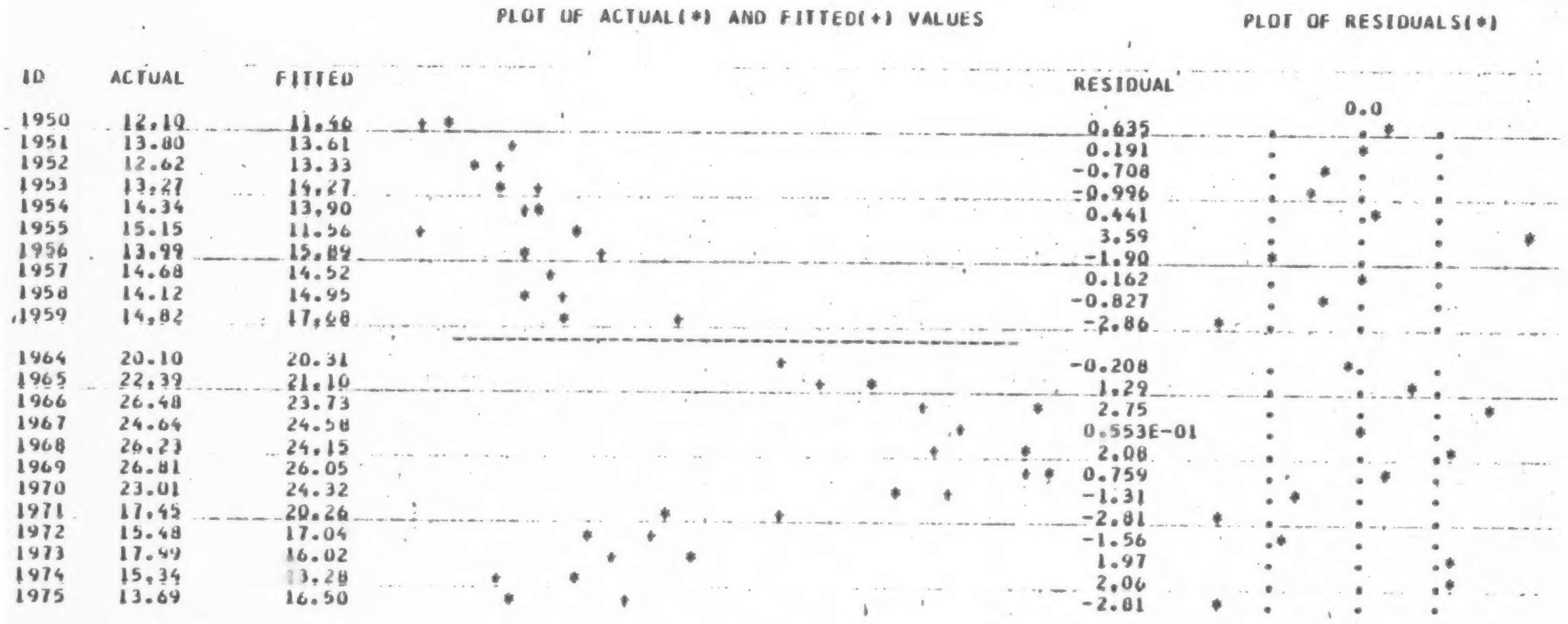
$R^2 = 0.8848$

F-statistic (5,16) = 24.5801

Durbin-Watson statistic = 1.3779

Standard error of the regression = 1.93008

Sum of squared residuals = 59.6031.



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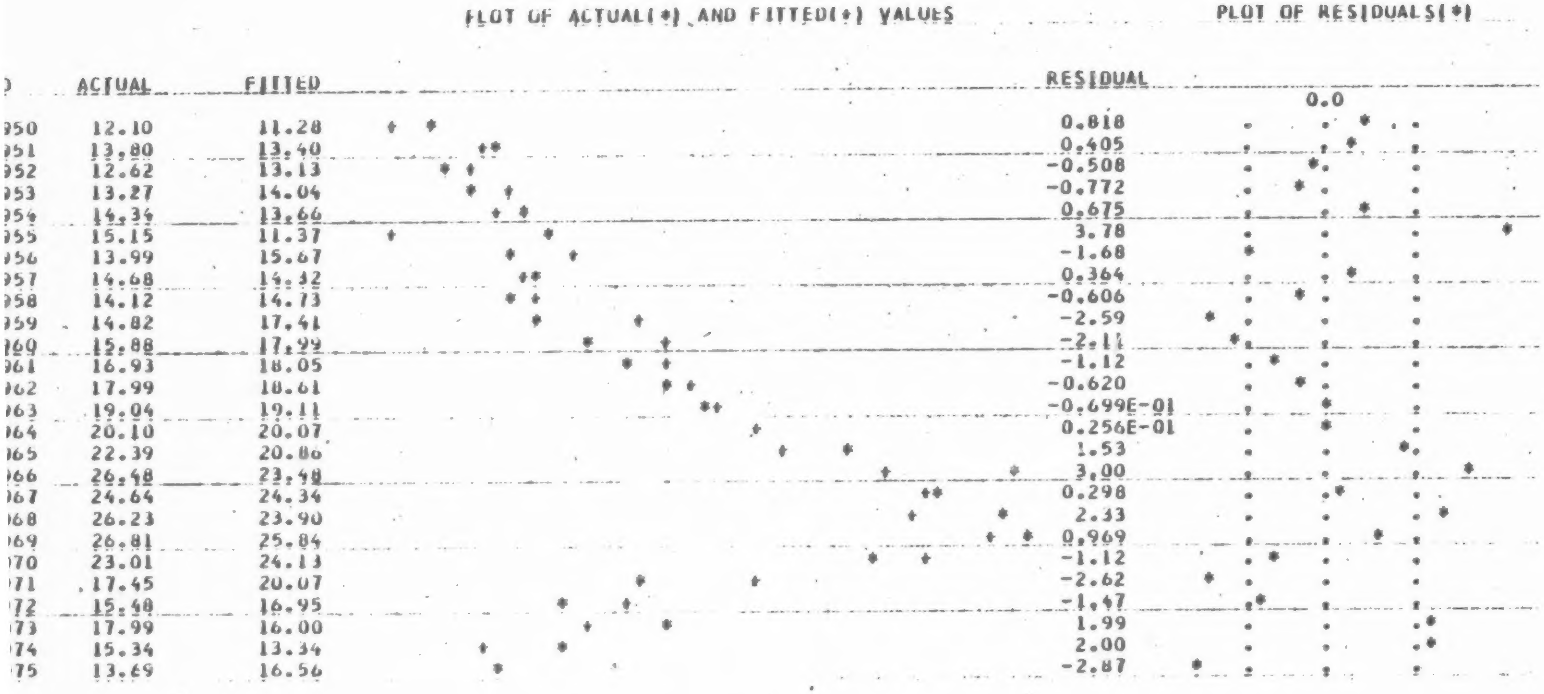
                                PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)
 ID     ACTUAL     FITTED                                          RESIDUAL
                                                                                         0.0
 1950   12.10      11.46                                           0.635
 1951   13.80      13.61                                           0.191
 1952   12.62      13.33                                          -0.708
 1953   13.27      14.27                                          -0.996
 1954   14.34      13.90                                           0.441
 1955   15.15      11.56                                           3.59
 1956   13.99      15.89                                          -1.90
 1957   14.68      14.52                                           0.162
 1958   14.12      14.95                                          -0.827
 1959   14.82      17.68                                          -2.86

 1964   20.10      20.31                                          -0.208
 1965   22.39      21.10                                           1.29
 1966   26.48      23.73                                           2.75
 1967   24.64      24.58                                           0.553E-01
 1968   26.23      24.15                                           2.08
 1969   26.81      26.05                                           0.759
 1970   23.01      24.32                                          -1.31
 1971   17.45      20.26                                          -2.81
 1972   15.48      17.04                                          -1.56
 1973   17.99      16.02                                           1.97
 1974   15.34      13.28                                           2.06
 1975   13.69      16.50                                          -2.81
```

Figure 103. Plots for Productivity Model Using Principal Components, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (OLS)



```
)      ACTUAL      FITTED       RESIDUAL
950     12.10       11.28        0.818
951     13.80       13.40        0.405
952     12.62       13.13       -0.508
953     13.27       14.04       -0.772
954     14.34       13.66        0.675
955     15.15       11.37        3.78
956     13.99       15.67       -1.68
957     14.68       14.32        0.364
958     14.12       14.73       -0.606
959     14.82       17.41       -2.59
960     15.88       17.99       -2.11
961     16.93       18.05       -1.12
962     17.99       18.61       -0.620
963     19.04       19.11       -0.699E-01
964     20.10       20.07        0.256E-01
965     22.39       20.86        1.53
966     26.48       23.48        3.00
967     24.64       24.34        0.298
968     26.23       23.90        2.33
969     26.81       25.84        0.969
970     23.01       24.13       -1.12
971     17.45       20.07       -2.62
972     15.48       16.95       -1.47
973     17.99       16.00        1.99
974     15.34       13.34        2.00
975     13.69       16.56       -2.87
```

gure 104. Plots for Productivity Model Using Principal Components, 1950 Through 1975: Western Kentucky (OLS)

Using estimated data in 1960 through 1963, the results are:

$$
\begin{aligned}
\text{(61E)}\quad PRY_t = {} & 6.27436 + 15.8958AP_t + 0.0313115\ CM_t \\
& (7.28269) \quad (4.7197)\#\#\#\#\#(0.113046) \\
& + 0.0395783\ DO_t - 0.208225\ PR_t \\
& (0.0397725) \qquad (0.0639063)\#\#\#\#\# \\
& - 0.199538\ MACT_t \\
& (0.0474743)\#\#\#\#\#
\end{aligned}
$$

$R^2 = 0.8824$

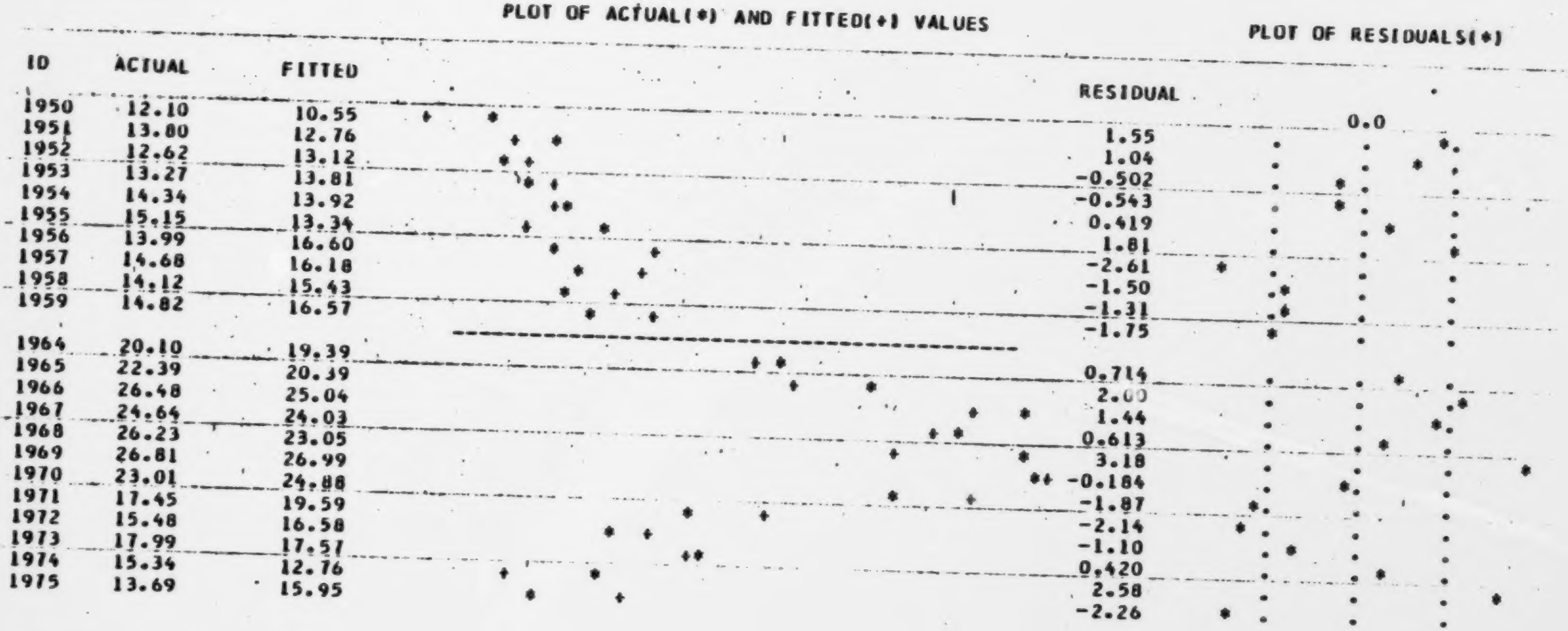
F-statistic (5,20) = 30.0018

Durbin-Watson statistic = 1.4063

Standard error of the regression = 1.75414

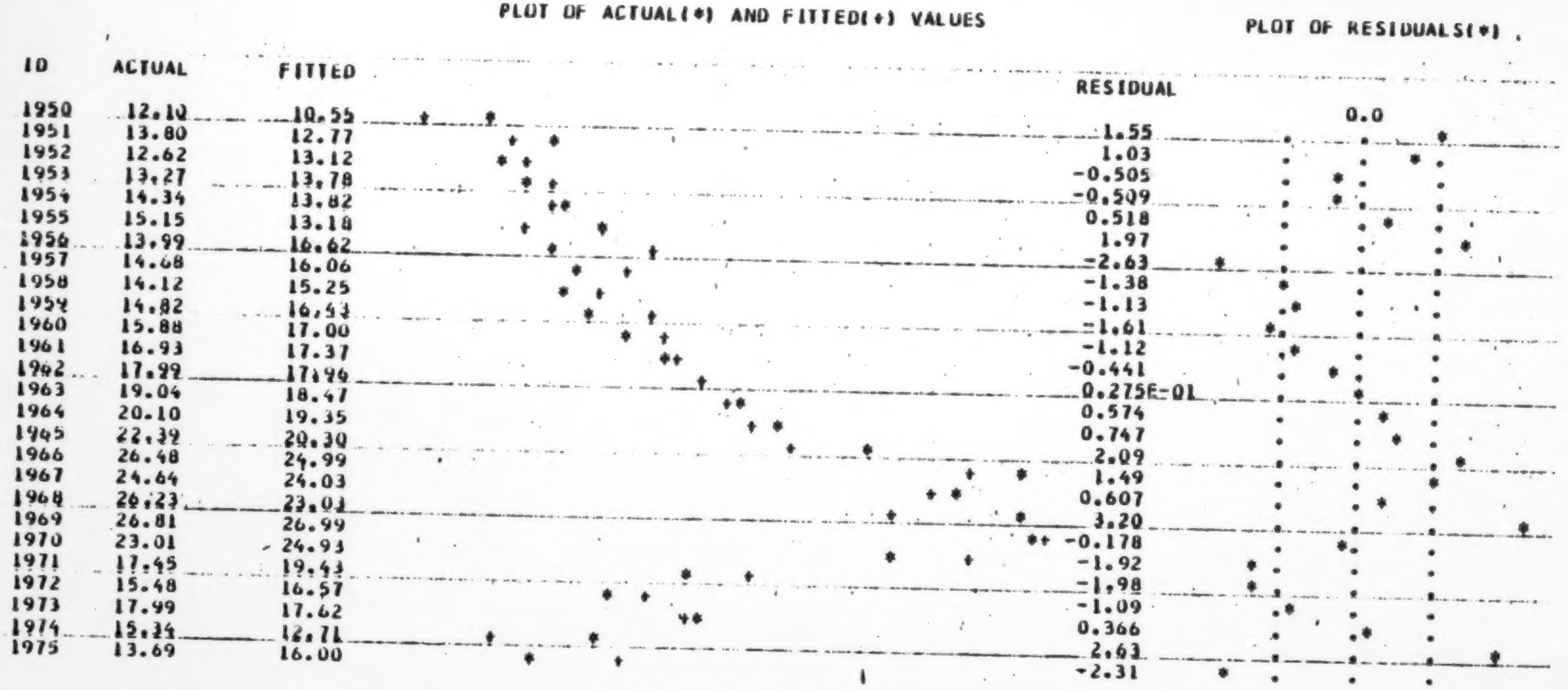
Sum of squared residuals = 61.5402.

The results of the two equations are similar. The coefficients of MACT and AP are significant at the 99.5 percent confidence levels. The coefficients of PR are significant in both equations at the 99.0 percent confidence levels or greater. All signs are as expected. The coefficients of CM and DO are not significant. The equations are significant at the 99.0 percent confidence level, and over 88.0 percent of the variation is explained. The Durbin-Watson test is inconclusive; however, the Hart-von Neumann statistics indicate that both equations have positive autocorrelation (95.0 percent confidence level). Appropriate plots are shown in Figures 105 and 106. The residuals plots show no evidence for the presence of heteroskedasticity.



```
                     PLOT OF ACTUAL(*) AND FITTED(+) VALUES
ID      ACTUAL      FITTED                                          PLOT OF RESIDUALS(*)
                                              RESIDUAL
1950    12.10       10.55                                      0.0
1951    13.80       12.76                        1.55
1952    12.62       13.12                        1.04
1953    13.27       13.81                      -0.502
1954    14.34       13.92                      -0.543
1955    15.15       13.34                       0.419
1956    13.99       16.60                        1.81
1957    14.68       16.18                       -2.61
1958    14.12       15.43                       -1.50
1959    14.82       16.57                       -1.31
                                                -1.75
1964    20.10       19.39
1965    22.39       20.39                       0.714
1966    26.48       25.04                        2.00
1967    24.64       24.03                        1.44
1968    26.23       23.05                       0.613
1969    26.81       26.99                        3.18
1970    23.01       24.88                      -0.184
1971    17.45       19.59                       -1.87
1972    15.48       16.58                       -2.14
1973    17.99       17.57                       -1.10
1974    15.34       12.76                       0.420
1975    13.69       15.95                        2.58
                                                -2.26
```

Figure 105. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (OLS)



```
                         PLOT OF ACTUAL(*) AND FITTED(+) VALUES                 PLOT OF RESIDUALS(*) .
ID     ACTUAL     FITTED
                                                                      RESIDUAL
                                                                                     0.0
1950   12.10      10.55                                                1.55
1951   13.80      12.77                                                1.03
1952   12.62      13.12                                               -0.505
1953   13.27      13.78                                               -0.509
1954   14.34      13.82                                                0.518
1955   15.15      13.18                                                1.97
1956   13.99      16.62                                               -2.63
1957   14.68      16.06                                               -1.38
1958   14.12      15.25                                               -1.13
1959   14.82      16.43                                               -1.61
1960   15.88      17.00                                               -1.12
1961   16.93      17.37                                               -0.441
1962   17.99      17.96                                                0.275E-01
1963   19.04      18.47                                                0.574
1964   20.10      19.35                                                0.747
1965   22.39      20.30                                                2.09
1966   26.48      24.99                                                1.49
1967   24.64      24.03                                                0.607
1968   26.23      23.03                                                3.20
1969   26.81      26.99                                               -0.178
1970   23.01      24.93                                               -1.92
1971   17.45      19.43                                               -1.98
1972   15.48      16.57                                               -1.09
1973   17.99      17.62                                                0.366
1974   15.34      12.71                                                2.63
1975   13.69      16.00                                               -2.31
```

Figure 106. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1975: Western Kentucky (OLS)

Correcting for autocorrelation with the Cochrane-Orcutt iterative method yields the following results using data from 1950 through 1959 and 1964 through 1975:

$$(62)\ PRY_t = 22.6080 + 16.3438\ AP_t + 0.140708\ CM_t$$

(6.80222) (3.75773)#####(0.213952)

$$- 0.0440022\ DO_t - 0.326367\ PR_t - 0.0558457\ MACT_t$$

(0.0292994) (0.148013) ### (0.0601692)

$R^2 = 0.9313$

F-statistic (5,14) = 37.9769

Durbin-Watson = 1.7586

Standard error of the regression = 1.53450

Sum of squared residuals = 32.9655.

Using estimated data in 1960 through 1963, the Cochrane-Orcutt iterative technique yields:

$$(62E)\ PRY_t = 25.4025 + 15.2464\ AP_t + 0.0938576\ CM_t$$

(6.09755) (3.39482)#####(0.120961)

$$- 0.0360417\ DO_t - 0.328129\ PR_t$$

(0.0279486) (0.0970186)#####

$$- 0.0864046\ MACT_t$$

(0.0523270)#

$R^2 = 0.9227$

F-statistic (5,19) = 45.3840

Durbin-Watson statistic = 1.4630

Standard error of the regression = 1.41348

Sum of squared residuals = 37.9608.

According to the Hart-von Neumann statistics, positive autocorrelation is remedied only in Equation 62. Equation 62E still has positive autocorrelation (95.0 percent confidence level). The coefficients of AP and PR are significant in both equations; that of MACT is significant only in Equation 62E. Coefficients of CM and DO are not significant. The only unexpected sign is for DO. The values of R^2 are 0.93 and 0.92 for Equations 62 and 62E, respectively. Both equations are significant at the 99.0 percent confidence level. Plots of actual and fitted values and residuals plots are shown in Figures 107 and 108. The residuals plots do not indicate the presence of heteroskedasticity.

Again, the principal components method is used to correct for multicollinearity. The factor loadings and results of the OLS regression of data from 1950 through 1959 and 1964 through 1975 are:

Variable	Factor Loadings
AP	0.96367
CM	0.93771
DO	0.91590
PR	-0.47850

$$(63)\ PRY_t = 19.8695 + 5.73704\ PC_t - 0.272002\ MACT_t$$
$$(0.514005)(0.563327)****(0.0344778)\#\#\#\#\#$$

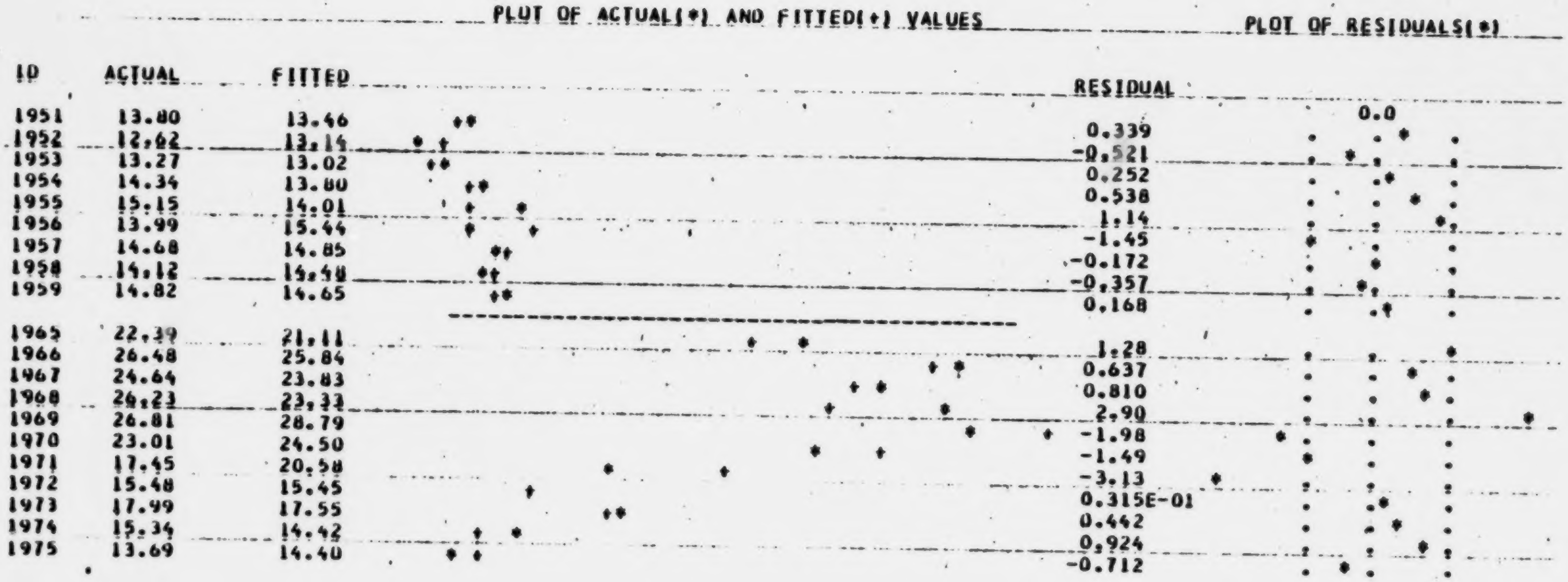
$R^2 = 0.8500$

F-statistic (2,19) = 53.8284

Durbin-Watson statistic = 1.6609

Standard error of the regression = 2.02121

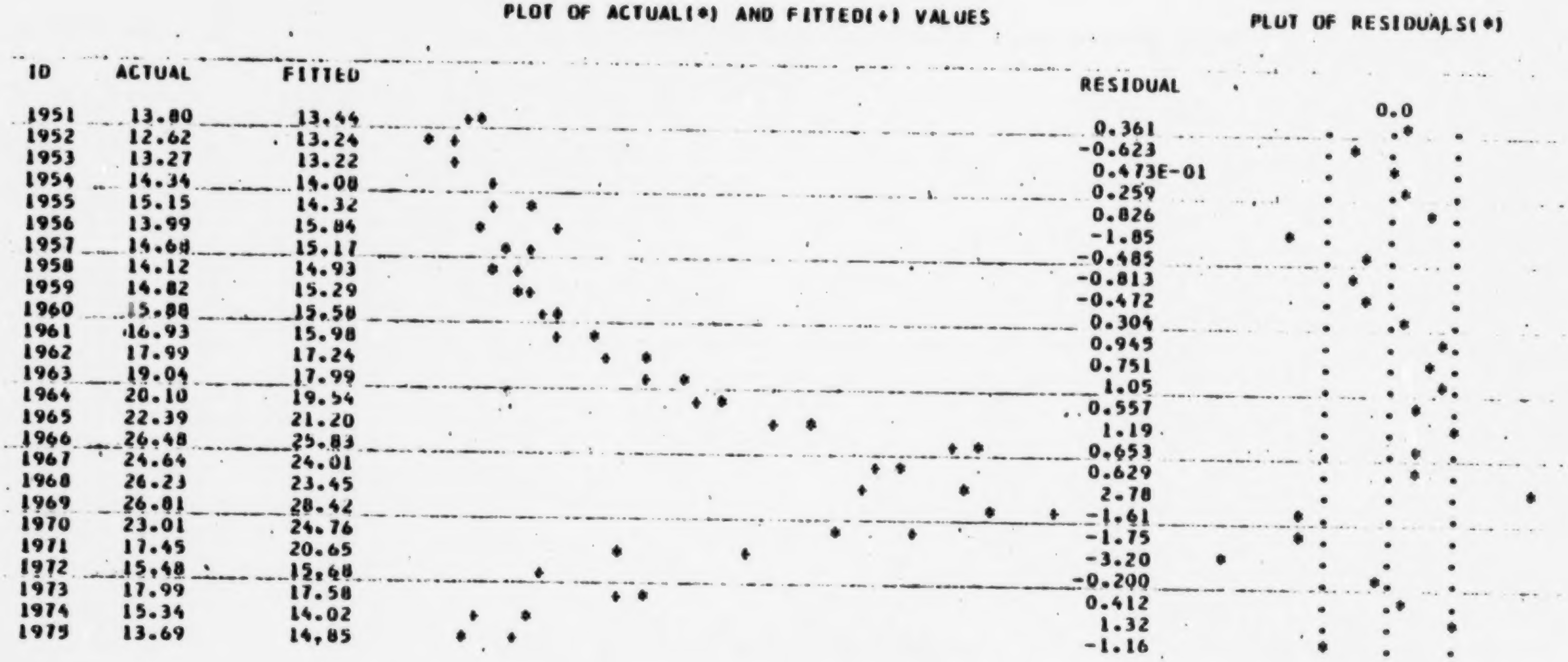
Sum of squared residuals = 77.6208.



```
                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID      ACTUAL      FITTED                              RESIDUAL
                                                                        0.0
1951    13.80       13.46                                0.339
1952    12.62       13.14                               -0.521
1953    13.27       13.02                                0.252
1954    14.34       13.80                                0.538
1955    15.15       14.01                                1.14
1956    13.99       15.44                               -1.45
1957    14.68       14.85                               -0.172
1958    14.12       14.48                               -0.357
1959    14.82       14.65                                0.168

1965    22.39       21.11                                1.28
1966    26.48       25.84                                0.637
1967    24.64       23.83                                0.810
1968    26.23       23.33                                2.90
1969    26.81       28.79                               -1.98
1970    23.01       24.50                               -1.49
1971    17.45       20.58                               -3.13
1972    15.48       15.45                                0.315E-01
1973    17.99       17.55                                0.442
1974    15.34       14.42                                0.924
1975    13.69       14.40                               -0.712
```

Figure 107. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (CORC)



```
                         PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLUT OF RESIDUALS(*)
ID     ACTUAL      FITTED                                            RESIDUAL
                                                                                          0.0
1951    13.80       13.44                                            0.361
1952    12.62       13.24                                           -0.623
1953    13.27       13.22                                            0.473E-01
1954    14.34       14.08                                            0.259
1955    15.15       14.32                                            0.826
1956    13.99       15.84                                           -1.85
1957    14.68       15.17                                           -0.485
1958    14.12       14.93                                           -0.813
1959    14.82       15.29                                           -0.472
1960    15.88       15.58                                            0.304
1961    16.93       15.98                                            0.945
1962    17.99       17.24                                            0.751
1963    19.04       17.99                                            1.05
1964    20.10       19.54                                            0.557
1965    22.39       21.20                                            1.19
1966    26.48       25.83                                            0.653
1967    24.64       24.01                                            0.629
1968    26.23       23.45                                            2.78
1969    26.81       28.42                                           -1.61
1970    23.01       24.76                                           -1.75
1971    17.45       20.65                                           -3.20
1972    15.48       15.68                                           -0.200
1973    17.99       17.58                                            0.412
1974    15.34       14.02                                            1.32
1975    13.69       14.85                                           -1.16
```

Figure 108. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1975: Western Kentucky (CORC)

The correlation matrix is:

	PC	MACT
PC	1.0000	0.62207
MACT	0.62207	1.0000

Using estimated data in 1960 through 1963, the results are:

Variable	Factor Loadings
AP	0.96371
CM	0.94028
DO	0.91945
PR	-0.43279

$$\text{(63E)}\ PRY_t = 19.5234 + 5.37783\ PC_t - 0.275577\ MACT_t$$
$$(0.426746)(0.485738)****(0.0318091)\#\#\#\#\#$$

$R^2 = 0.8465$

F-statistic (2,23) = 63.4245

Durbin-Watson statistic = 1.6530

Standard error of the regression = 1.86842

Sum of squared residuals = 80.2925.

The correlation matrix is:

	PC	MACT
PC	1.0000	0.63888
MACT	0.63888	1.0000

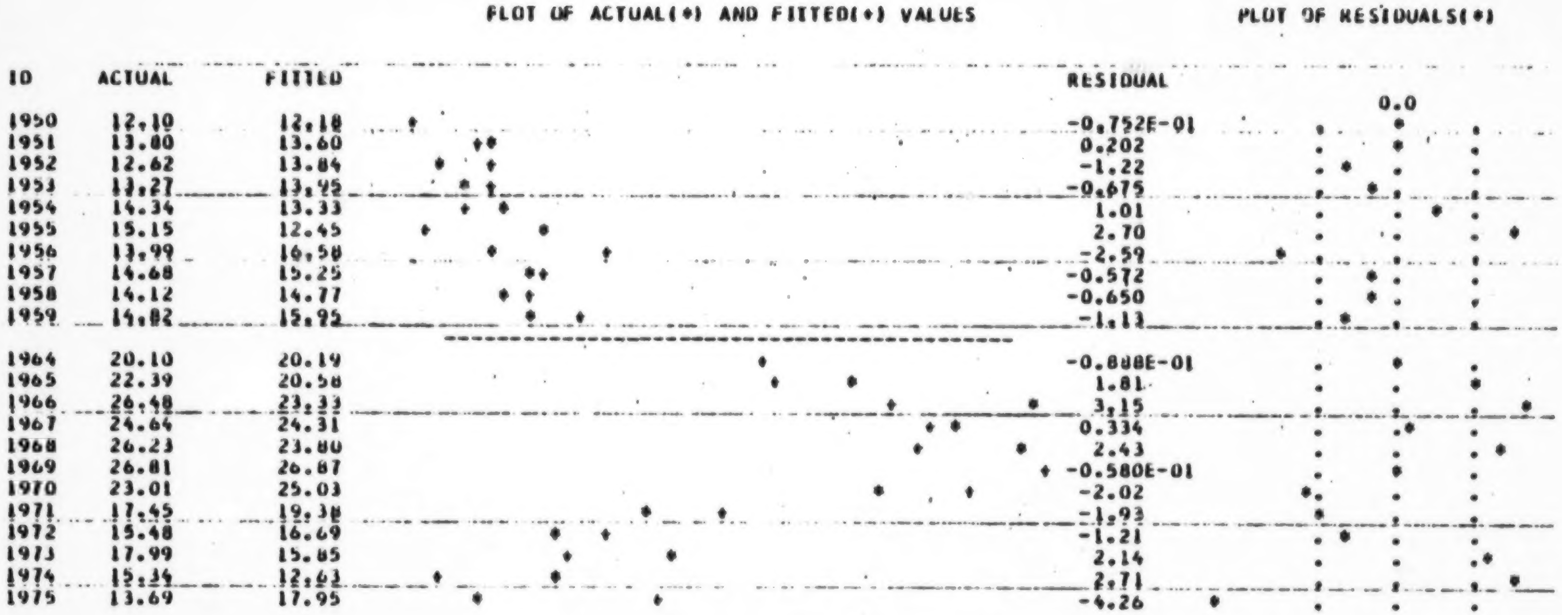
The coefficients of PC and MACT are significant at the 99.0 and 99.5 percent confidence levels, respectively, and the sign for MACT are as expected. The equations are significant at the 99.0 percent confidence level, and around 85.0 percent of the variation is explained. Neither regression has the problem of autocorrelation. The degree of correlation between PC and MACT is low in both equations. Appropriate plots are shown in Figures 109 and 110. There is no evidence for the presence of heteroskedasticity.

Results of Regressions for Underground Rail-Connected and Truck Mines Using Data Through 1975

Data used and results are presented in summary form for regressions using data for all mines (truck and rail mines combined) in Tables 54, 55, and 56. As explained for eastern Kentucky, these data are available only in 1964 through 1975; the number of degrees of freedom for the full model is only five.

Results of Regression Using Data Through 1969 and Predictions of Productivity

Derivations of predictions of productivity in 1970 through 1975 without the Act are presented in this section. First, time trends of productivity through 1969 are used to predict possible levels of productivity; second, estimates are made of the multivariate model using data through 1969. Predictions are made using values of the independent variables in 1970 through 1975. Third, predictions are made based on the results of the regression using data through 1975 by subtracting the negative influence of MACT on productivity. It is possible that the legislation could have indirect effects on productivity by affecting the



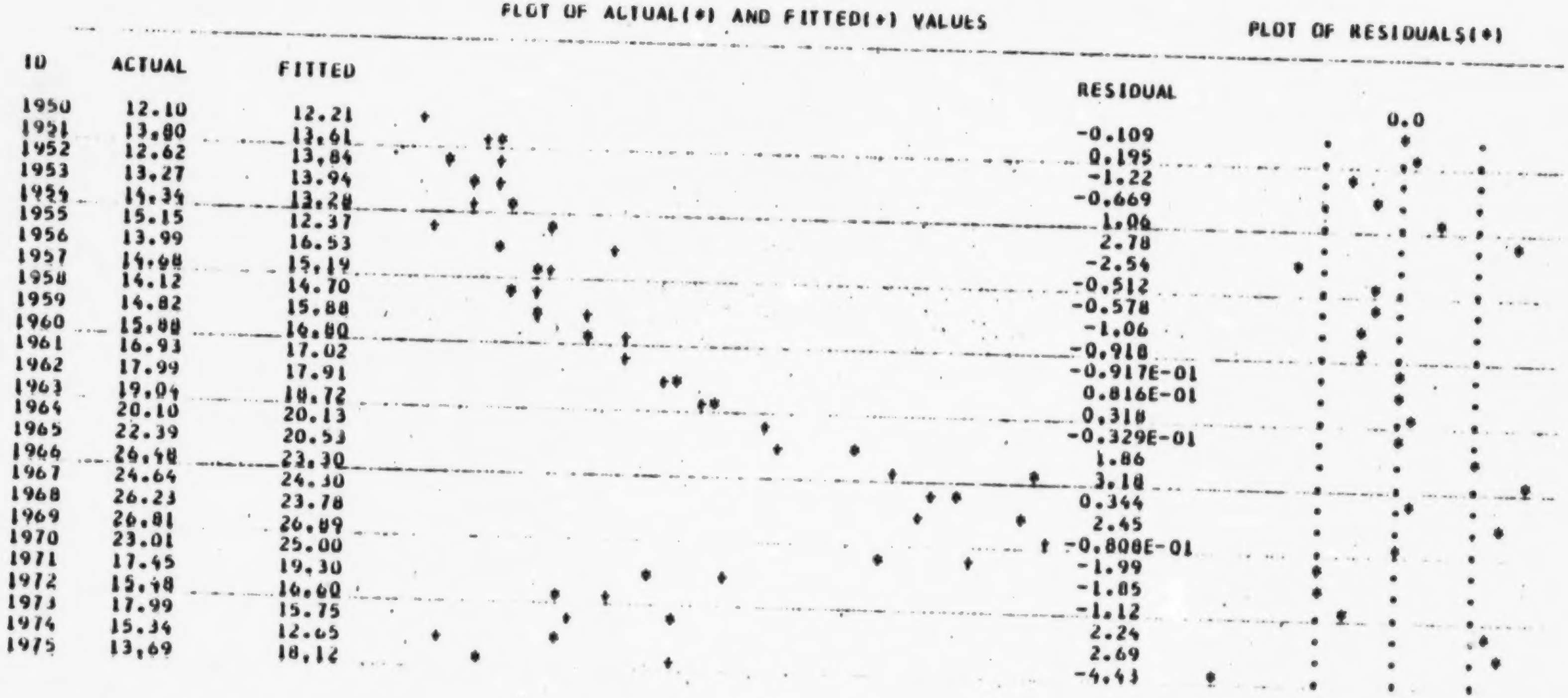
```
                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                RESIDUAL

1950    12.10       12.18                                 -0.752E-01
1951    13.80       13.60                                  0.202
1952    12.62       13.84                                 -1.22
1953    13.27       13.95                                 -0.675
1954    14.34       13.33                                  1.01
1955    15.15       12.45                                  2.70
1956    13.99       16.58                                 -2.59
1957    14.68       15.25                                 -0.572
1958    14.12       14.77                                 -0.650
1959    14.82       15.95                                 -1.13

1964    20.10       20.19                                 -0.888E-01
1965    22.39       20.58                                  1.81
1966    26.48       23.33                                  3.15
1967    24.64       24.31                                  0.334
1968    26.23       23.80                                  2.43
1969    26.81       26.87                                 -0.580E-01
1970    23.01       25.03                                 -2.02
1971    17.45       19.38                                 -1.93
1972    15.48       16.69                                 -1.21
1973    17.99       15.85                                  2.14
1974    15.34       12.63                                  2.71
1975    13.69       17.95                                 -4.26
```

Figure109. Plots for Productivity Model Excluding Seam Thickness Using Principal Components, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (OLS)



ID	ACTUAL	FITTED	RESIDUAL
1950	12.10	12.21	-0.109
1951	13.80	13.61	0.195
1952	12.62	13.84	-1.22
1953	13.27	13.94	-0.669
1954	14.34	13.28	1.06
1955	15.15	12.37	2.78
1956	13.99	16.53	-2.54
1957	14.68	15.19	-0.512
1958	14.12	14.70	-0.578
1959	14.82	15.88	-1.06
1960	15.88	16.80	-0.918
1961	16.93	17.02	-0.917E-01
1962	17.99	17.91	0.816E-01
1963	19.04	18.72	0.318
1964	20.10	20.13	-0.329E-01
1965	22.39	20.53	1.86
1966	26.48	23.30	3.18
1967	24.64	24.30	0.344
1968	26.23	23.78	2.45
1969	26.81	26.89	-0.808E-01
1970	23.01	25.00	-1.99
1971	17.45	19.30	-1.85
1972	15.48	16.60	-1.12
1973	17.99	15.75	2.24
1974	15.34	12.65	2.69
1975	13.69	18.12	-4.43

Figure 110. Plots for Productivity Model Excluding Seam Thickness Using Principal Components, 1950 Through 1975: Western Kentucky (OLS)

Table 54

Data for Western Kentucky, Underground Rail-Connected and Truck Mines

Year	Productivity PRY (tons per man-day)	Average Production AP[a] (tons)	Weighted-Average Seam Thickness ST (inches)	Percent Mined by Continuous Miners CM (percent)	Weighted-Average Days in Operation DO	Actual Price of Coal, 1975 Dollars PR_A (cents per million Btu)	Price of Coal Under the Assumption of No-Act 1975 Dollars PR (cents per million Btu)	Number of Inspections Per Mine Under CMHSA MACT
1964	19.49	267454	61.53	12.55	229	28.7	28.7	0.0
1965	21.55	290031	61.08	14.02	220	27.7	27.7	0.0
1966	24.77	354872	60.48	12.16	225	27.0	27.0	0.0
1967	23.67	392349	60.28	15.71	238	27.7	27.7	0.0
1968	25.36	468553	60.34	17.37	236	27.0	27.0	0.0
1969	26.31	661132	60.76	19.15	245	27.1	27.1	0.0
1970	22.30	607203	61.07	17.88	249	30.8	24.1	5.15924
1971	17.38	560648	60.71	20.81	220	33.5	26.2	10.4678
1972	15.64	587455	61.63	22.62	241	35.4	27.7	29.2330
1973	18.09	824527	61.47	21.99	253	37.1	29.0	42.6833
1974	15.61	831658	61.23	30.92	246	54.4	42.6	52.0947
1975	14.25	915396	62.32	31.85	264	64.2	50.3	39.1479

Table 55

Results of Regressions Summary for Western Kentucky: Underground Rail-Connected and Truck Mines Using Data Through 1975

Equation	Constant	AP	ST	CM	DO	PR	MACT	PC	R^2	S	SSR	Autocorrelation (Durbin-Watson Statistic)	F-Statistic
68(OLS)	248.054	10.033	-4.072 **	-0.574	0.099	0.153	-0.103 #		0.93	1.65	13.55	None(2.34)	$11.03_{(6,5)}$
69(OLS)	22.858						-0.167 ##	-0.051	0.65	2.73	66.94	+(1.24)	$8.47_{(2,9)}$
70(CORC)	23.074						-0.153 ##	-0.646	0.75	2.46	48.42	None(1.60)	$11.87_{(2,8)}$
71(OLS)	19.027	15.731		-0.542	0.019	0.046	-0.180 ##		0.78	2.68	43.03	None(1.49)	$4.18^{+}_{(5,6)}$
72(CORC)	22.721	9.308		-0.610	0.017	0.094	-0.129		0.84	2.49	31.03	None(1.69)	$5.19_{(5,5)}$
73(OLS)	23.445						-0.207 ###	0.879	0.67	2.68	64.53	None(1.36)	$8.95_{(2,9)}$

$^{+}$The F-statistic indicates this equation is not significant.

Significance Levels:
** Significant at 95.0 percent confidence level (two-tail test)
# Significant at 90.0 percent confidence level (one-tail test)
Significant at 95.0 percent confidence level (one-tail test)
Significant at 97.5 percent confidence level (one-tail test)

Table 56

Ninety-Five Percent Confidence Intervals for Coefficients in Western Kentucky Regressions: Underground Rail-Connected and Truck Mines

Equation	AP		ST		CM		DO		PR		MACT		PC	
68(OLS)	-13.11	33.17	-7.25	-0.90	-1.39	0.24	-0.10	0.30	-0.20	0.51	-0.25	0.04		
69(OLS)											-0.35	0.01	-3.66	3.55
70(CORC)											-0.34	0.03	-4.01	2.72
71(OLS)	-19.43	50.89			-1.80	0.71	-0.28	0.32	-0.49	0.58	-0.39	0.03		
72(CORC)	-21.76	40.37			-1.83	0.61	-0.24	0.27	-0.52	0.70	-0.37	0.11		
73(OLS)											-0.38	-0.04	-2.55	4.30

other independent variables. To examine this possibility, the trend of each variable is reexamined. From Figures 72, 99, and 100, it is seen that CM, DO, and AP have increasing trends overall, with no breaks in 1969. No break in trend in 1969 is evident for ST (Figure 98). The effect of the Mine Act on price has been accounted for as described in previous sections. Thus, it seems unlikely that the Mine Act had large, if any, effects on the other independent variables.

Productivity has an increasing trend before 1969. A simple regression of productivity on time (T) from 1(1950) through 10(1959) and 15(1964) through 20(1969) was made. The results are:

$$(64)\ PRY_t = \underset{(0.842320)}{9.77626} + \underset{(0.0711890)^{****}}{0.806999T}$$

$R^2 = 0.9018$

F-statistic (1,14) = 128.505

Durbin-Watson statistic = 0.7399

Standard error of the regressions = 1.80095

Sum of squared residuals = 45.4081.

Using estimated data in 1960 through 1963, the results are:

$$(64E)\ PRY_t = \underset{(0.873982)}{9.57963} + \underset{(0.0729586)^{****}}{0.779939T}$$

$R^2 = 0.8639$

F-statistic (1,18) = 114.279

Durbin-Watson statistic = 0.4950

Standard error of the regression = 1.88143

Sum of squared residuals = 63.7159.

Both equations have positive autocorrelation (See Figures 111 and 112). To remedy the autocorrelation, the Cochrane-Orcutt technique is used. The results are:

$$(65)\quad PRY_t = \underset{(2.25431)}{7.89964} + \underset{(0.169221)^{****}}{0.945743T}$$

$R^2 = 0.9416$

F-statistic (1,12) = 193.357

Durbin-Watson statistic = 2.0614

Standard error of the regression = 1.43561

Sum of squared residuals = 24.7317.

The results of the Cochrane-Orcutt iterative technique using estimated data in 1960 through 1963 are:

$$(65E)\quad PRY_t = \underset{(3.05203)}{6.61503} + \underset{(0.203702)^{****}}{0.984740T}$$

$R^2 = 0.9406$

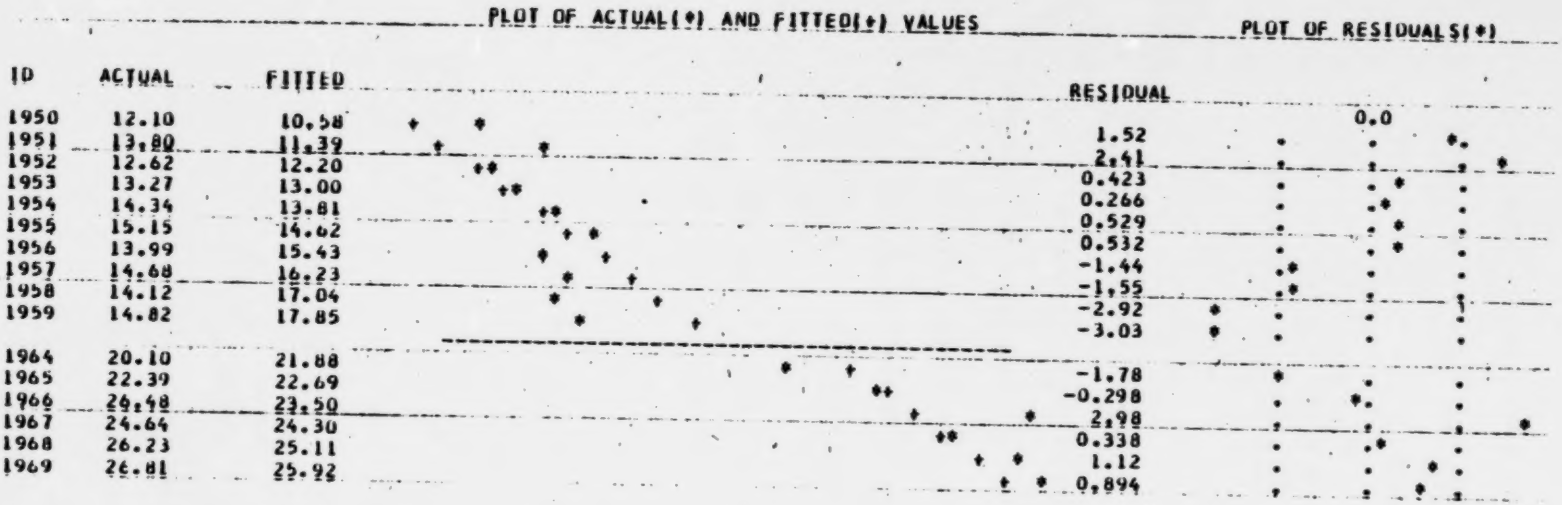
F-statistic (1,17) = 268.959

Durbin-Watson statistic = 2.2569

Standard error of the regression = 1.23253

Sum of squared residuals = 25.8252.

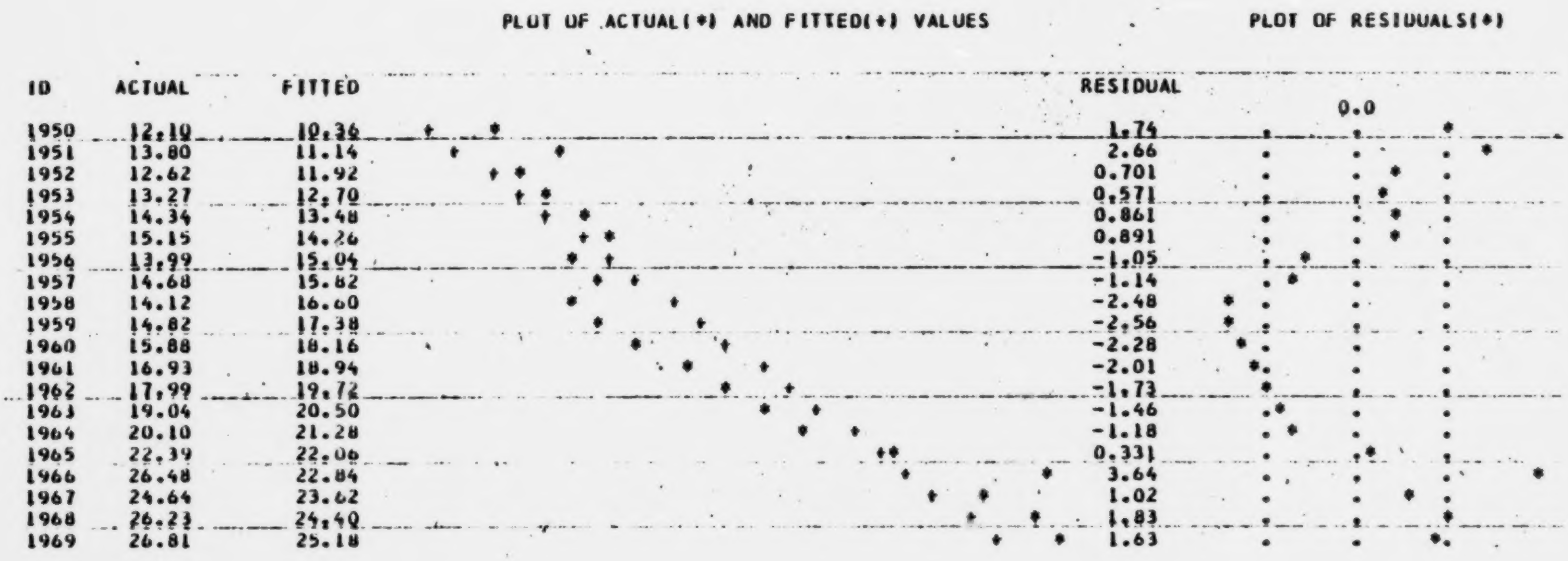
Neither equation has autocorrelation. Over 94.0 percent of the variation in productivity is explained; both equations are significant at the 99.0 percent confidence level. Appropriate plots are shown in Figures 113 and 114. There is no evidence for the presence of heteroskedasticity.



```
PLOT OF ACTUAL(*) AND FITTED(+) VALUES                PLOT OF RESIDUALS(*)
ID      ACTUAL     FITTED                 RESIDUAL
                                                              0.0
1950    12.10      10.58                    1.52
1951    13.80      11.39                    2.41
1952    12.62      12.20                    0.423
1953    13.27      13.00                    0.266
1954    14.34      13.81                    0.529
1955    15.15      14.62                    0.532
1956    13.99      15.43                   -1.44
1957    14.68      16.23                   -1.55
1958    14.12      17.04                   -2.92
1959    14.82      17.85                   -3.03

1964    20.10      21.88                   -1.78
1965    22.39      22.69                   -0.298
1966    26.48      23.50                    2.98
1967    24.64      24.30                    0.338
1968    26.23      25.11                    1.12
1969    26.81      25.92                    0.894
```

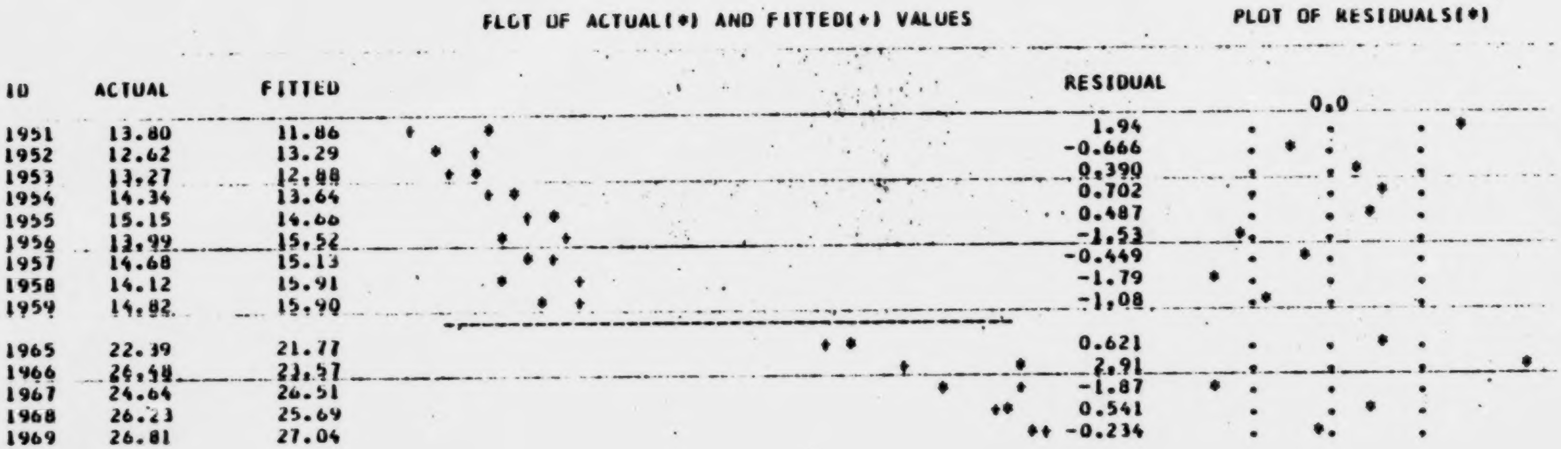
Figure 111. Plots for Time Trend of Productivity, 1950 Through 1959 and 1964 Through 1969: Western Kentucky (OLS)



```
                         PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)

ID      ACTUAL     FITTED                                        RESIDUAL
                                                                                   0.0
1950    12.10      10.36                                          1.74
1951    13.80      11.14                                          2.66
1952    12.62      11.92                                          0.701
1953    13.27      12.70                                          0.571
1954    14.34      13.48                                          0.861
1955    15.15      14.26                                          0.891
1956    13.99      15.04                                         -1.05
1957    14.68      15.82                                         -1.14
1958    14.12      16.60                                         -2.48
1959    14.82      17.38                                         -2.56
1960    15.88      18.16                                         -2.28
1961    16.93      18.94                                         -2.01
1962    17.99      19.72                                         -1.73
1963    19.04      20.50                                         -1.46
1964    20.10      21.28                                         -1.18
1965    22.39      22.06                                          0.331
1966    26.48      22.84                                          3.64
1967    24.64      23.62                                          1.02
1968    26.23      24.40                                          1.83
1969    26.81      25.18                                          1.63
```

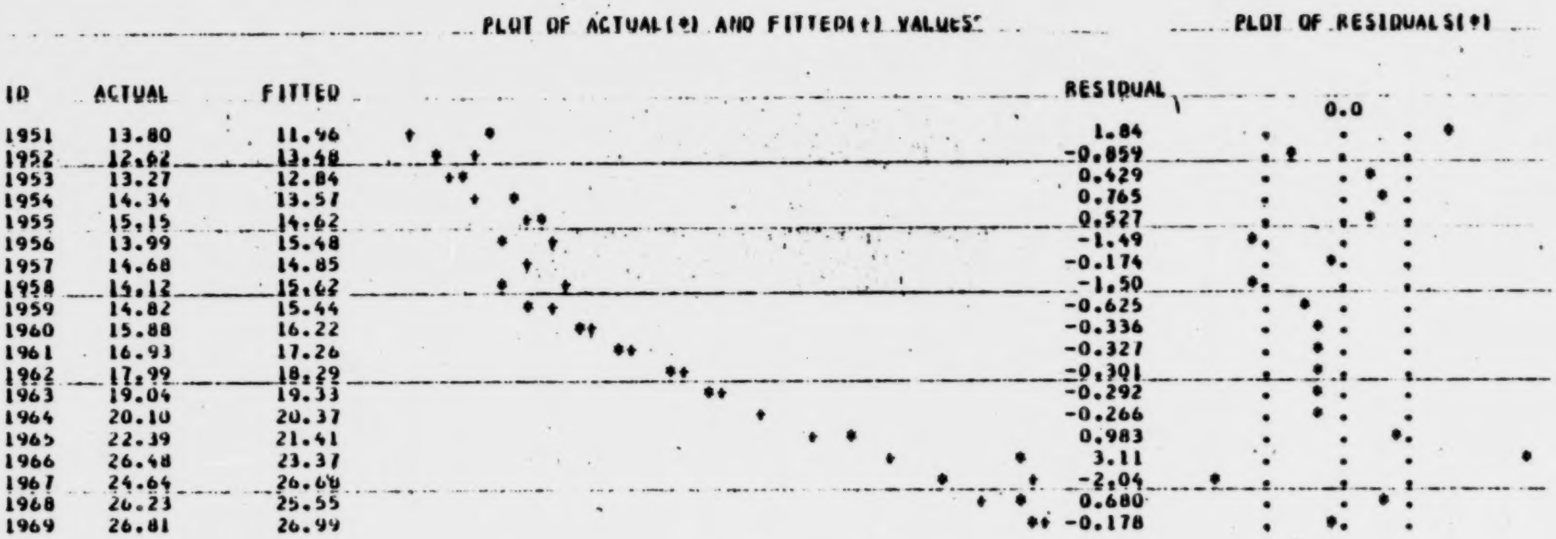
Figure112. Plots for Time Trend of Productivity, 1950 Through 1969: Western Kentucky (OLS)



```
                                  FLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)
ID      ACTUAL     FITTED                                              RESIDUAL
                                                                                          0.0
1951    13.80      11.86                                                 1.94
1952    12.62      13.29                                                -0.666
1953    13.27      12.88                                                 0.390
1954    14.34      13.64                                                 0.702
1955    15.15      14.66                                                 0.487
1956    13.99      15.52                                                -1.53
1957    14.68      15.13                                                -0.449
1958    14.12      15.91                                                -1.79
1959    14.82      15.90                                                -1.08

1965    22.39      21.77                                                 0.621
1966    26.48      23.57                                                 2.91
1967    24.64      26.51                                                -1.87
1968    26.23      25.69                                                 0.541
1969    26.81      27.04                                                -0.234
```

Figure 113. Plots for Time Trend of Productivity, 1950 Through 1959 and 1964 Through 1969: Western Kentucky (CORC)



ID	ACTUAL	FITTED	RESIDUAL
1951	13.80	11.96	1.84
1952	12.62	13.48	-0.859
1953	13.27	12.84	0.429
1954	14.34	13.57	0.765
1955	15.15	14.62	0.527
1956	13.99	15.48	-1.49
1957	14.68	14.85	-0.174
1958	14.12	15.62	-1.50
1959	14.82	15.44	-0.625
1960	15.88	16.22	-0.336
1961	16.93	17.26	-0.327
1962	17.99	18.29	-0.301
1963	19.04	19.33	-0.292
1964	20.10	20.37	-0.266
1965	22.39	21.41	0.983
1966	26.48	23.37	3.11
1967	24.64	26.68	-2.04
1968	26.23	25.55	0.680
1969	26.81	26.99	-0.178

Figure114. Plots for Time Trend of Productivity, 1950 Through 1969: Western Kentucky (CORC)

Predictions were made using the time trends (Table 54). They are for increasing productivities through time that are significantly greater than actual values in all years.

A regression was run for 1950 through 1959 and 1964 through 1969 with productivity as a function of average production, weighted-average seam thickness, percent mined by continuous miners, weighted-average days in operation, and price. The results are:

$$(66)\ PRY_t = -0.827716 + 13.0056\ AP_t + 0.0497472\ ST_t$$
$$(35.3170) \quad (5.76271)\#\#\# \quad (0.515457)$$

$$+ 0.349404\ CM_t \ \ 0.0328263\ DO_t - 0.0600304\ PR_t$$
$$(0.231045)\# \quad (0.0547471) \quad (0.175245)$$

$R^2 = 0.9390$

F-statistic (5,10) = 30.7719

Durbin-Watson statistic = 1.5518

Standard error of the regression = 1.67951

Sum of squared residuals = 28.2074.

Using estimated data in 1960 through 1963, the results are:

$$(66E)\ PRY_t = -\ 11.2996 + 13.2273\ AP_t + 0.182414\ ST_t$$
$$(26.3193) \quad (4.58277)\#\#\#\# \quad (0.395609)$$

$$+ 0.326431\ CM_t + 0.0467132\ DO_t - 0.0850833\ PR_t$$
$$(0.185998)\# \quad (0.0441966) \quad (0.138047)$$

Table 57

Comparison of Predicted Levels of Productivity Based on a Time Trend and on Multiple Regressions With Actual Levels of Productivity in Western Kentucky for Underground Rail-Connected Mines

Year	Actual	Based on Simple Time Trend for 1950 Through 1959 and 1964 Through 1969 (CORC)	Based on Simple Time Trend for 1950 Through 1969 (CORC)	Based on AP, ST, CM, DO, and PR for 1950 Through 1959 and 1964 Through 1969 (OLS)	Based on AP, ST, CM, DO, and PR for 1950 Through 1969 (OLS)	Based on AP, CM, DO, and PR for 1950 Through 1959 and 1964 Through 1969 (OLS)	Based on AP, CM, DO, and PR for 1950 Through 1969 (OLS)
1970	23.01	27.76 (±3.69)	27.29 (±3.18)	26.88 (±4.75)	27.17 (±3.93)	26.82 (±4.27)	26.90 (±3.60)
1971	17.45	28.71 (±3.77)	28.28 (±3.27)	24.39 (±5.52)	24.04 (±4.57)	24.38 (±5.19)	23.96 (±4.41)
1972	15.48	29.65 (±3.85)	29.26 (±3.35)	25.91 (±5.92)	25.92 (±4.92)	25.83 (±5.31)	25.60 (±4.55)
1973	17.99	30.60 (±3.93)	30.25 (±3.44)	28.91 (±5.60)	29.09 (±4.52)	28.82 (±4.85)	28.78 (±4.14)
1974	15.34	31.54 (±4.02)	31.23 (±3.54)	30.80 (±13.13)	30.30 (±10.01)	30.71 (±12.21)	30.22 (±9.68)
1975	13.69	32.49 (±4.10)	32.22 (±3.64)	32.60 (±15.69)	32.32 (±11.68)	32.44 (±14.37)	32.09 (±11.25)

$R^2 = 0.9351$

F-statistic (5,14) = 40.3505

Durbin-Watson statistic = 1.6347

Standard error of the regression = 1.47318

Sum of squared residuals = 30.3835.

In both equations the coefficients of AP and CM are significant, but those of ST, DO and PR are not significant. All signs are as expected. Almost 94.0 percent of the variation is explained; both equations are significant at the 99.0 percent confidence level. The Durbin-Watson tests are inconclusive; however, the Hart-von Neumann statistics indicate that neither equation has autocorrelation. The correlation matrices for Equations 66 and 66E are shown in Tables 58, and 59, respectively. The highest pairwise correlations are between PR and CM, ST and CM, CM and AP, PR and ST, and PR and AP. Plots of actual and fitted values and residuals plots are shown in Figures 115 and 116. There is no evidence for the presence of heteroskedasticity.

Eliminating ST, the results are:

$$\begin{aligned} (67)\ PRY_t = {} & \underset{(8.20111)}{2.47821} + \underset{(5.42626)\#\#\#}{12.9166\ AP_t} + \underset{(0.212530)\#}{0.343499\ CM_t} \\ & + \underset{(0.0515379)}{0.0319728\ DO_t} - \underset{(0.164819)}{0.0572055\ PR_t} \end{aligned}$$

$R^2 = 0.9389$

F-statistic (4,11) = 42.2694

Durbin-Watson statistic = 1.5545

Standard error of the regression = 1.60209

Sum of squared residuals = 28.2337.

Table 58

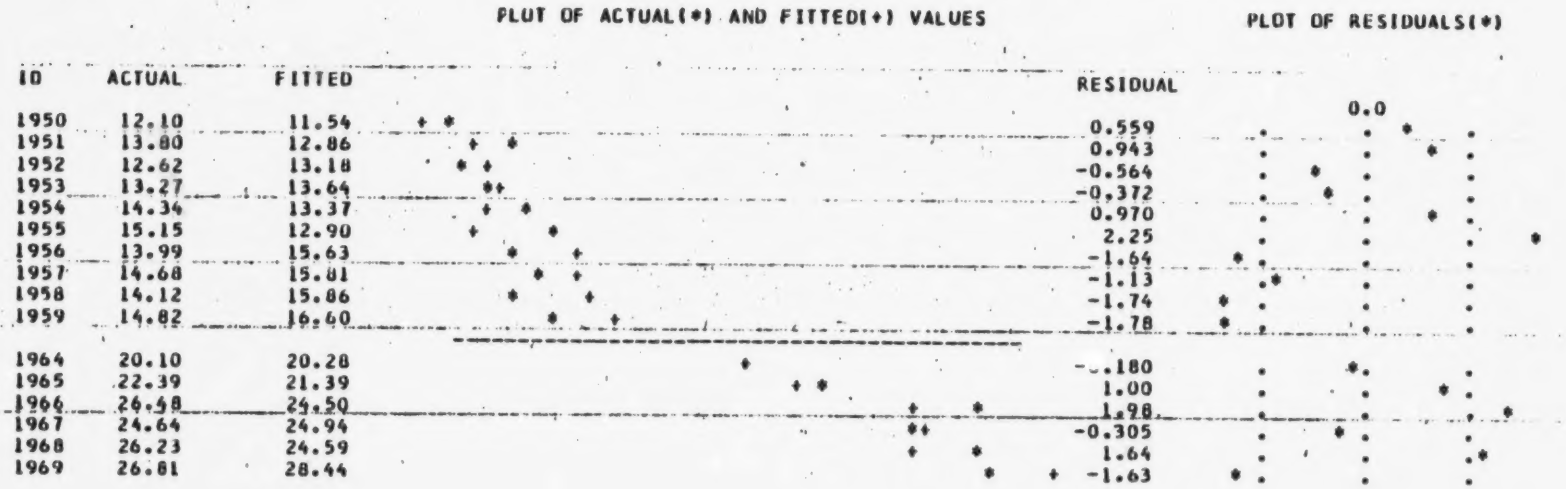
Pairwise Correlation Matrix for AP, ST, CM, DO, and PR: Western Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1969)

	AP	ST	CM	DO	PR
AP	1.0000	-0.83813	0.87517	0.77768	-0.81949
ST	-0.83813	1.0002	-0.88489	-0.71330	0.82901
CM	0.87517	-0.88489	1.0000	0.74212	-0.91167
DO	0.77768	-0.71330	0.74212	1.0000	-0.54249
PR	-0.81949	0.82901	-0.91167	-0.54249	1.0000

Table 59

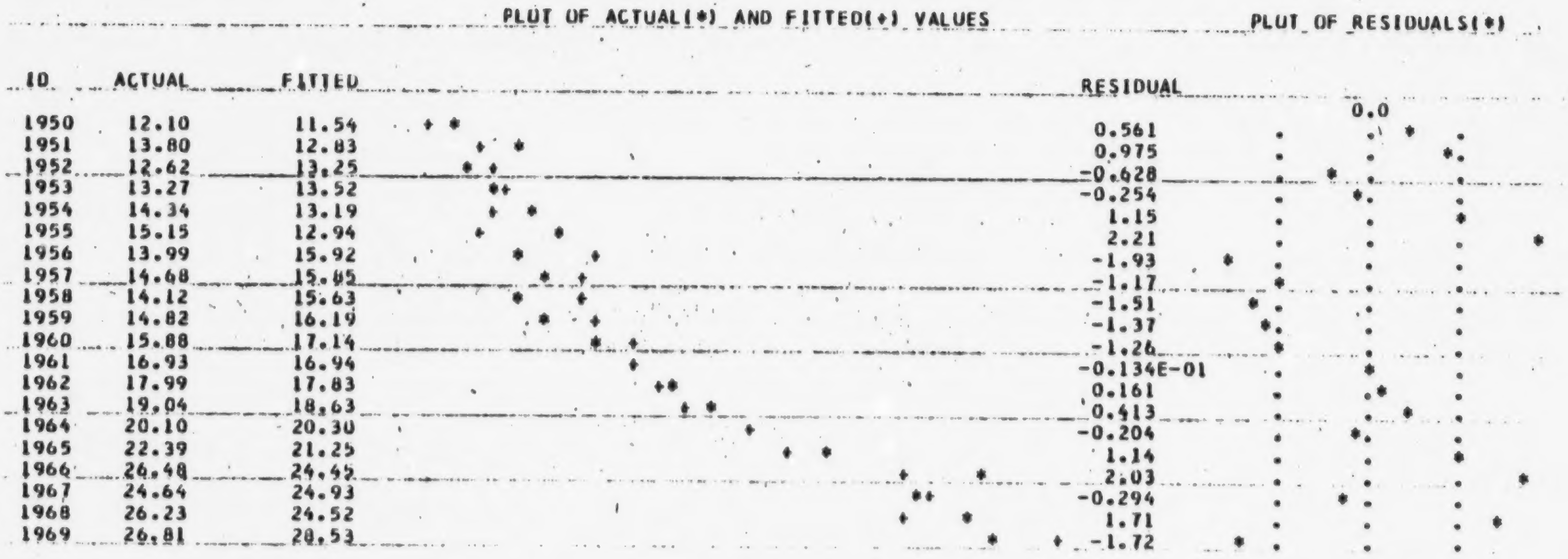
Pairwise Correlation Matrix for AP, ST, CM, DO, and PR: Western Kentucky Underground Rail-Connected Mines (1950 Through 1969)

	AP	ST	CM	DO	PR
AP	1.0000	-0.76966	0.86332	0.77117	-0.77628
ST	-0.76966	1.0002	-0.85825	-0.64783	0.83486
CM	0.86332	-0.85825	1.0000	0.72748	-0.89885
DO	0.77117	-0.64783	0.72748	1.0000	-0.51593
PR	-0.77628	0.83486	-0.89885	-0.51593	1.0000



ID	ACTUAL	FITTED	RESIDUAL
1950	12.10	11.54	0.559
1951	13.80	12.86	0.943
1952	12.62	13.18	-0.564
1953	13.27	13.64	-0.372
1954	14.34	13.37	0.970
1955	15.15	12.90	2.25
1956	13.99	15.63	-1.64
1957	14.68	15.81	-1.13
1958	14.12	15.86	-1.74
1959	14.82	16.60	-1.78
1964	20.10	20.28	-0.180
1965	22.39	21.39	1.00
1966	26.48	24.50	1.98
1967	24.64	24.94	-0.305
1968	26.23	24.59	1.64
1969	26.81	28.44	-1.63

Figure 115. Plots for Productivity Model, 1950 Through 1959 and 1964 Through 1969: Western Kentucky (OLS)



PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(*)

ID	ACTUAL	FITTED	RESIDUAL
1950	12.10	11.54	0.561
1951	13.80	12.83	0.975
1952	12.62	13.25	-0.628
1953	13.27	13.52	-0.254
1954	14.34	13.19	1.15
1955	15.15	12.94	2.21
1956	13.99	15.92	-1.93
1957	14.68	15.85	-1.17
1958	14.12	15.63	-1.51
1959	14.82	16.19	-1.37
1960	15.88	17.14	-1.26
1961	16.93	16.94	-0.134E-01
1962	17.99	17.83	0.161
1963	19.04	18.63	0.413
1964	20.10	20.30	-0.204
1965	22.39	21.25	1.14
1966	26.48	24.45	2.03
1967	24.64	24.93	-0.294
1968	26.23	24.52	1.71
1969	26.81	28.53	-1.72

Figure 116. Plots for Productivity Model, 1950 Through 1969: Western Kentucky (OLS)

Using estimated data in 1960 through 1963, the results are:

$$(67E)\ PRY_t = \underset{(7.03368)}{0.369878} + \underset{(4.46067)\#\#\#\#\#}{13.2075\ AP_t}\ \underset{(0.177810)\#}{0.310254\ CM_t}$$

$$+ \underset{(0.0421477)}{0.0426278\ DO_t} - \underset{(0.126281)}{0.0633250\ PR_t}$$

$R^2 = 0.9341$

F-statistic (4,15) = 53.1762

Durbin-Watson statistic = 1.6359

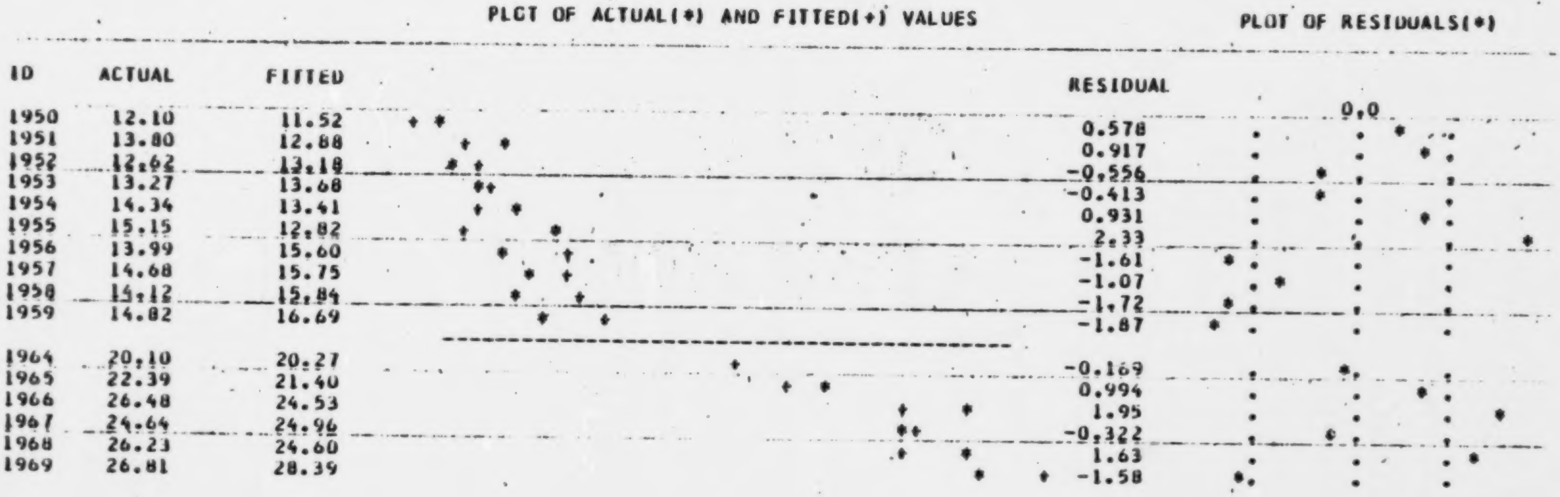
Standard error of the regression = 1.43399

Sum of squared residuals = 30.8450.

The coefficients of AP and CM are significant; those of DO and PR are not significant. All signs are as expected. Almost 94.0 percent of the variance is explained; both equations are significant at the 99.0 percent confidence level. There is no autocorrelation, according to the Hart-von Neumann statistics; the Durbin-Watson tests are inconclusive. Appropriate plots are shown in Figures 117 and 118. The residuals plots show no evidence for the presence of heteroskedasticity.

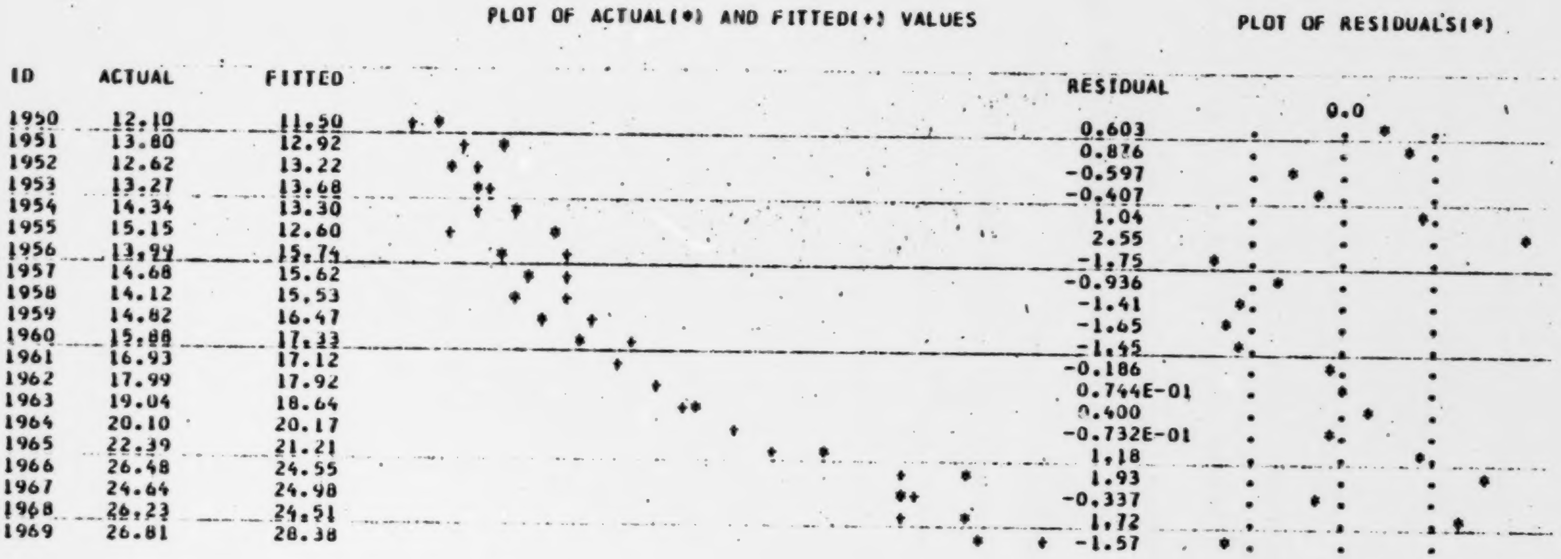
Comparisons of Equations 66 with 67 and 66E with 67E indicate that ST is not significant in explaining productivity; the appropriate F-statistics for testing full versus reduced models are $0.009_{(1,10)}$ and $0.213_{(1,14)}$, respectively.

Predictions based on these equations are shown in Table 57. The predictions are for values that are significantly greater than actual values in 1971 through 1975. In 1970, only the predicted values based on



ID	ACTUAL	FITTED	RESIDUAL
1950	12.10	11.52	0.578
1951	13.80	12.88	0.917
1952	12.62	13.18	-0.556
1953	13.27	13.68	-0.413
1954	14.34	13.41	0.931
1955	15.15	12.82	2.33
1956	13.99	15.60	-1.61
1957	14.68	15.75	-1.07
1958	14.12	15.84	-1.72
1959	14.82	16.69	-1.87
1964	20.10	20.27	-0.169
1965	22.39	21.40	0.994
1966	26.48	24.53	1.95
1967	24.64	24.96	-0.322
1968	26.23	24.60	1.63
1969	26.81	28.39	-1.58

Figure 117. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1959 and 1964 Through 1969: Western Kentucky (OLS)



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                                   PLOT OF ACTUAL(*) AND FITTED(+) VALUES            PLOT OF RESIDUALS(*)
ID      ACTUAL       FITTED                                               RESIDUAL
                                                                                           0.0
1950    12.10        11.50                                                 0.603
1951    13.80        12.92                                                 0.876
1952    12.62        13.22                                                -0.597
1953    13.27        13.68                                                -0.407
1954    14.34        13.30                                                 1.04
1955    15.15        12.60                                                 2.55
1956    13.99        15.74                                                -1.75
1957    14.68        15.62                                                -0.936
1958    14.12        15.53                                                -1.41
1959    14.82        16.47                                                -1.65
1960    15.88        17.33                                                -1.45
1961    16.93        17.12                                                -0.186
1962    17.99        17.92                                                 0.744E-01
1963    19.04        18.64                                                 0.400
1964    20.10        20.17                                                -0.732E-01
1965    22.39        21.21                                                 1.18
1966    26.48        24.55                                                 1.93
1967    24.64        24.98                                                -0.337
1968    26.23        24.51                                                 1.72
1969    26.81        28.38                                                -1.57
```

Figure 118. Plots for Productivity Model Excluding Seam Thickness, 1950 Through 1969: Western Kentucky (OLS)

regressions using estimated data are significantly greater than actual values. In 1975, these predictions are as high as those from the time trend.

Data for all underground mines cannot be used to predict productivities in 1970 through 1975 by this method, since there are only six observations (1964 through 1969) and five independent variables plus a constant. This leaves zero degrees of freedom.

Using the results of the model for data through 1975, predictions of productivity without the Mine Act were made by adding the productivity lost due to MACT to the prediction of productivity for 1970 through 1975. These predictions for underground rail-connected mines are shown in Table 60. The predictions are for productivities that are greater than actual values in all years, with the prediction in 1975 of 22.91 tons per man-day. For comparison, the effects of PR on productivity are also shown in Table 60. The results show that the Mine Act had a greater effect, in general, on productivity when the means of the two are compared. This analysis is also presented for truck and rail-connected mines (Table 61). Again, the predicted productivities are greater than actual values in all years. The reduction in productivity appears to be greater for rail-connected mines than for truck mines in western Kentucky since the coefficient of MACT has a greater absolute value for rail-connected mines (0.186) than for all mines (0.103). In terms of percentage losses in productivity due to MACT, there are larger losses in every year for rail-connected mines, also (Table 62). For example, in 1975 the results indicate that productivity was down due to the Mine Act by around 21.3 percent for all mines and by around 31.8 percent for rail mines only.

Table 60

Effect of MACT and PR on Productivity in Underground Rail-Connected Mines: Western Kentucky*

Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT	Mean		(2) Value of MACT	Tons per man-day: (3) Reduction in Productivity Caused by MACT -[(1) x (2)] Low	Mean	High	(4) Prediction of Productivity from Model	(5) Prediction of Productivity Without MACT (3) + (4) Low	Mean	High	(6) Actual Productivity
1969	-0.067	-0.186	-0.304	0				26.70				26.81
1970				5.15924	0.35	0.96	1.57	24.55	24.90	25.51	26.12	23.01
1971				10.4678	0.70	1.95	3.18	19.65	20.35	21.60	22.83	17.45
1972				29.2330	1.96	5.44	8.89	16.47	18.43	21.91	25.36	15.48
1973				42.6833	2.86	7.94	12.98	17.56	20.42	25.50	30.54	17.99
1974				52.0947	3.49	9.69	15.84	13.09	16.58	22.78	28.93	15.34
1975				39.1479	2.26	7.28	11.90	15.63	18.25	22.91	27.53	13.69

Year	(7) 95.0 Percent Confidence Interval for Coefficient of PR	Mean		Cents Per Million Btu: (8) Value of PR	(9) Change in PR From 1969	Tons Per Man-Day: (10) Reduction in Productivity Caused by Change in PR -((7) x (9)) Low	Mean	High
1969	0.006	-0.173	-0.352	27.1				
1970				24.1	-3.0	0.018	-0.519	-1.056
1971				26.2	-0.9	0.005	-0.156	-0.317
1972				27.7	0.6	-0.004	0.104	0.211
1973				29.0	1.9	-0.011	0.329	0.669
1974				42.6	15.5	-0.093	2.682	5.456
1975				50.3	23.2	-0.139	4.014	8.166

---

*Using results of Equation 59.

Table 61

Effect of MACT on Productivity in Underground Rail-Connected and Truck Mines: Western Kentucky*

					Tons per man-day							
Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Productivity Caused by MACT -((1) x (2))			(4) Prediction of Productivity from Model (95.0 percent confidence level)	(5) Prediction of Productivity Without MACT (4) + (3)			(6) Actual Productivity
		Mean			Low	Mean	High		Low	Mean	High	
1969	-0.251	-0.103	0.045	0				24.61				26.31
1970				5.15924	-0.23	0.53	1.29	22.94	22.71	23.47	24.23	22.30
1971				10.4678	-0.47	1.08	2.63	19.17	18.70	20.25	21.80	17.38
1972				29.2330	-1.32	3.01	7.34	15.03	13.71	18.04	22.37	15.64
1973				42.6833	-1.92	4.40	10.71	18.42	16.50	22.82	29.13	18.09
1974				52.0947	-2.34	5.37	13.08	14.76	12.42	20.13	27.84	15.61
1975				39.1479	-1.76	4.03	9.83	14.92	13.16	18.95	24.75	14.25

*Using results of Equation 68. PR does not have a negative effect on productivity in this case, since the coefficient is positive.

Table 62

Percentage Losses in Productivity Due to the Mine Act in Western Kentucky

Year	Rail Mines Using Predictions of Regression 59 (Data Through 1975) (percentage loss)	All Mines Using Predictions of Regression 68 (Data Through 1975) (percentage loss)
1970	3.8	2.3
1971	9.0	5.3
1972	24.8	16.7
1973	31.1	19.3
1974	42.5	26.7
1975	31.8	21.3
Average Per Year	23.8	15.3

Summary

Some of the results of the regressions are summarized in Tables 63, 64, and 65. The relationships of the independent variables to productivity in the model using data on rail-connected mines for 1950 through 1959 and 1964 through 1975 may be summarized as follows:

(1) average production is positively related and significant;

(2) weighted-average seam thickness is negatively related and not significant;

(3) percent mined by continuous miners is negatively related (positively in the regression excluding seam thickness) and not significant;

(4) weighted-average days in operation is positively related (negatively in the regression excluding seam thickness) and not significant;

(5) price is negatively related and significant; and

(6) the Mine-Act variable is negatively related and significant.

The regression analyses indicate that the effects of each independent variable on productivity in terms of appropriate magnitude are:

(1) an increase in average production of 0.1 million tons increases productivity by 1.5 tons per man-day;

(2) an increase in weighted-average seam thickness of 1.0 inch decreases productivity by 0.5 tons per man-day;

(3) an increase in percent of coal mined by continuous miners of 1.0 decreases productivity by 0.10 tons per man-day (increases productivity by 0.1 tons per man-day in the regression excluding seam thickness);

Table 63

Results of Regressions Summary for Western Kentucky: Underground Rail-Connected Mines Using Data Through 1975

Equation	Constant	AP	ST	CM	DO	PR	MACT	PC	R^2	S	SSR	Autocorrelation (Durbin-Watson Statistic)	F-Statistic
59(OLS)	36.801	15.085 ####	-0.463	-0.008	0.031	-0.173 ##	-0.186 #####		0.89	1.95	56.86	None(1.50)	$20.25_{(6,15)}$
59E(OLS)	22.375	15.601 #####	-0.261	0.002	0.039	-0.185 ###	-0.191 #####		0.88	1.78	60.43	+(1.46)	$24.25_{(6,19)}$
60(OLS)	19.545						-0.232 #####	5.391 ****	0.87	1.92	69.76	None(1.64)	$60.97_{(2,19)}$
60E(OLS)	19.197						-0.228 #####	4.961 ****	0.85	1.83	76.87	None(1.49)	$66.76_{(2,23)}$
61(OLS)	7.602	15.961 #####		0.039	0.033	-0.209 ####	-0.200 #####		0.88	1.93	59.60	+(1.38)	$24.58_{(5,16)}$
61E(OLS)	6.274	15.896 #####		0.031	0.040	-0.208 #####	0.200 #####		0.88	1.75	61.54	+(1.41)	$30.00_{(5,20)}$
62(CORC)	22.608	16.344 #####		0.141	-0.044	-0.326 ###	-0.056		0.93	1.53	32.97	None(1.76)	$37.98_{(5,14)}$
62E(CORC)	25.403	15.246 #####		0.094	-0.036	-0.328 #####	-0.086 #		0.92	1.41	37.96	+(1.46)	$45.38_{(5,19)}$
63(OLS)	19.870						-0.272 #####	5.737 ****	0.85	2.02	77.62	None(1.66)	$53.83_{(2,19)}$
63E(OLS)	19.523						-0.276 #####	5.378 ****	0.85	1.87	80.29	None(1.65)	$63.42_{(2,23)}$

Significance Levels:
**** Significant at 99.0 percent confidence level (two-tail test)
# Significant at 90.0 percent confidence level (one-tail test)
Significant at 95.0 percent confidence level (one-tail test)
Significant at 97.5 percent confidence level (one-tail test)
Significant at 99.0 percent confidence level (one-tail test)
Significant at 99.5 percent confidence level (one-tail test)

Table 64

Results of Regressions Summary for Western Kentucky: Underground Rail-Connected Mines Using Data Through 1969

Equation	Constant	AP	ST	CM	DO	PR	T	R^2	S	SSR	Autocorrelation (Durbin-Watson Statistic)	F-Statistic
64(OLS)	9.776						0.807 ****	0.90	1.80	45.41	+(0.74)	$128.51_{(1,14)}$
64E(OLS)	9.580						0.780 ****	0.86	1.88	63.72	+(0.50)	$114.28_{(1,18)}$
65(CORC)	7.900						0.946 ****	0.94	1.44	24.73	None(2.06)	$193.36_{(1,12)}$
65E(CORC)	6.615						0.985 ****	0.94	1.23	25.83	None(2.26)	$268.96_{(1,17)}$
66(OLS)	-0.828	13.006 ###	0.050	0.349 #	0.033	-0.060		0.94	1.68	28.21	None(1.55)	$30.77_{(5,10)}$
66E(OLS)	-11.300	13.227 ####	0.182	0.326 #	0.047	-0.085		0.94	1.47	30.38	None(1.47)	$40.35_{(5,14)}$
67(OLS)	2.478	12.917 ###		0.343 #	0.032	-0.057		0.94	1.60	28.23	None(1.55)	$42.27_{(4,11)}$
67E(OLS)	0.370	13.208 #####		0.310 #	0.043	-0.063		0.93	1.43	30.85	None(1.64)	$53.18_{(4,15)}$

Significance Levels:
**** Significant at 99.0 percent confidence level (two-tail test)
# Significant at 90.0 percent confidence level (one-tail test)
Significant at 97.5 percent confidence level (one-tail test)
Significant at 99.0 percent confidence level (one-tail test)
Significant at 99.5 percent confidence level (one-tail test)

Table 65

Ninety-Five Percent Confidence Intervals for Coefficients in Western Kentucky Regressions: Underground Rail-Connected Mines

Equation	AP		ST		CM		DO		PR		MACT		PC		T	
							Using Data Through 1975									
59(OLS)	3.42	26.75	-1.62	0.70	-0.30	0.29	-0.07	0.13	-0.35	0.01	-0.30	-0.07				
59E(OLS)	5.50	25.70	-1.18	0.66	-0.26	0.27	-0.05	0.13	-0.35	-0.02	-0.30	-0.08				
60(OLS)											-0.29	-0.17	4.35	6.43		
60E(OLS)											-0.29	-0.17	4.06	5.86		
61(OLS)	4.66	27.26			-0.23	0.31	-0.06	0.13	-0.36	-0.06	-0.31	-0.09				
61E(OLS)																
62(CORC)	8.28	24.40			-0.32	0.60	-0.11	0.02	-0.64	-0.01	-0.18	0.07				
62E(CORC)	8.14	22.35			-0.16	0.35	-0.65	0.58	-0.53	-0.12	-0.20	0.02				
63(OLS)											-0.34	-0.20	4.56	6.92		
63E(OLS)											-0.34	-0.21	4.37	6.38		
							Using Data Through 1969									
64(OLS)															0.65	0.96
64E(OLS)															0.63	0.93
65(CORC)															0.58	1.31
65E(CORC)															0.56	1.41
66(OLS)	0.17	25.85	-1.10	1.20	-0.17	0.86	-0.09	0.15	-0.45	0.33						
66E(OLS)	3.41	32.88	-0.67	1.03	-0.07	0.72	-0.05	0.14	-0.38	0.21						
67(OLS)	0.97	24.86			-0.12	0.81	-0.08	0.15	-0.42	0.31						
67E(OLS)	3.70	22.71			-0.07	0.69	-0.05	0.13	-0.33	0.21						

(4) an increase in weighted-average days in operation by 10.0 increases productivity by 0.3 tons per man-day (decreases productivity by 0.4 tons per man-day in the regression excluding seam thickness;

(5) an increase in the price of coal by 1.0 cent per million Btu decreases productivity by approximately 0.2 tons per man-day; and

(6) an increase in the severity of CMHSA enforcement as approximated by the number of inspections per mine by 10.0 decreases productivity by 1.9 tons per man-day.

Results of the regressions using estimated data in 1960 through 1964 are similar to these.

The relationship of the independent variables to productivity in the model using data for all mines for 1964 through 1975 may be summarized as follows:

(1) average production is positively related and not significant;

(2) weighted-average seam thickness is negatively related and significant;

(3) percent mined by continuous miners is negatively related and not significant;

(4) weighted-average days in operation is positively related and not significant;

(5) price is positively related and not significant; and

(6) the Mine-Act variable is negatively related and significant.

The regression analyses indicate that the effects of each independent variable on productivity in terms of approximate magnitude are:

(1) an increase in average production of 0.1 million tons increases productivity by 1.0 tons per man-day;

(2) an increase in weighted-average seam thickness of 1.0 inch decreases productivity by 4.0 tons per man-day (this result seems highly unlikely);

(3) an increase in percent of coal mined by continuous miners of 1.0 decreases productivity by 0.6 tons per man-day;

(4) an increase in weighted-average days in operation of 10.0 increases productivity by 0.2 tons per man-day;

(5) an increase in the price of coal by 1.0 cent per million Btu increases productivity by 0.1 tons per man-day; and

(6) an increase in the severity of enforcement of CMHSA as approximated by the number of inspections per man-day by 10.0 decreases productivity by 1.3 tons per man-day.

Predictions of productivity based on the model using data through 1969 are for values that are significantly greater than actual values in 1971 through 1975 (Table 57). These results indicate that productivity was down in 1970 through 1975 by the following approximate percentages, respectively: 14.0, 29.0, 40.0, 38.0, 50.0, and 58.0; this is an average of around 38.0 percent per year.

Predictions of productivity based on the model including seam thickness and using data through 1975 for rail-connected mines are greater than actual values in all years, but they are not as high as those derived from the model using data through 1969. These results indicate that productivity was down in rail-connected mines in 1970 through 1975 by the following approximate percentages, respectively: 4.0, 9.0, 25.0, 31.0, 43.0 and 32.0; this is an average of around 24.0 percent per year. In all mines, the corresponding percentage losses were: 2.0, 5.0, 17.0, 19.0, 27.0, and 21.0, respectively, for an average of around 15.0 percent per year. Percentage losses in productivity due to the Mine Act are summarized in Table 62.

CHAPTER IV

RESULTS OF INJURY MODEL

In this chapter, analyses of state data and the results of regressions of the injury model presented in Chapter II are presented for West Virginia, Pennsylvania, Illinois, Ohio, eastern Kentucky, and western Kentucky. Regressions are made on data from 1950 through 1975, and predictions of injury rates are made for 1970 through 1975 using the results. The negative influence of the Mine-Act variable is subtracted from the prediction of injury rate made by the model. Regressions are also made using data from 1950 through 1969. Assuming there was no Coal Mine Health and Safety Act, predictions of injury rates are made for 1970 through 1975 using the estimated multivariate model. All predictions are compared to actual rates.

Methods and Procedures

The procedures used for the investigation of the injury rate model are the same as those used in Chapter III for the productivity model. For each state, data are presented, and the trends of the dependent and independent variables are described. In this chapter, the regression results are presented in tabular form, and the pairwise correlation matrices and plots of actual and fitted values and plots of residuals are presented. Ordinary least squares regressions were made, and if autocorrelation was present according to the Durbin-Watson or Hart-von Neumann statistics, the Cochrane-Orcutt technique was employed. A principal component was used to remedy multicollinearity. The significance of each equation was determined from the F-statistic and is indicated in footnotes only for equations that are not significant at a 95.0 percent confidence level or greater. Residuals were examined for evidence of heteroskedasticity.

West Virginia

Data and Trends of Variables

The data used for West Virginia are presented in Table 66. The state data on injuries, total production, and average production man-days worked, weighted-average seam thickness, and weighted-average employment were obtained from the West Virginia Department of Mines Annual Report for the years 1950 through 1975. Other data sources are as given in the section on methods of investigation.

The trends over time of the accident rates studied are shown in Figures 119 through 124. Nonfatal injury rates per million man-hours (Figure 119) show an overall level to slowly increasing trend over time. There is no statistical evidence for a break in trend in 1969. Using piecewise regression with a join point of 1969, the results are:

$$(1)\ NFRMH_t = \underset{(332.0)}{-497.0} + \underset{(0.170)}{0.285}\, X_1 - \underset{(0.754)}{0.890}\, X_2\, (X_1 - 1969)$$

$R^2 = 0.109$

F-statistic (2,23) = 1.41

Standard error of the regression = 4.69.

Nonfatal injury rates per million tons (Figure 120) follow a downward trend from 1950 (74.0) thorugh 1968 (28.6), then an overall upward trend through 1975 (53.2). A break in trend in 1969 from decreasing to increasing rates is significant at the 99.0 percent confidence level:

Table 66

Data for West Virginia Injury Model

Year	Number of Nonfatal Injuries NFTL	Nonfatal Injury Rate Per Million Man-Hours NFRMH	Nonfatal Injury Rate Per Million Tons NFRPR	Total Number of Fatal Injuries FTL	Number of Disaster Fatalities DFTL	Fatal Injury Rate Per Million Man-Hours FRMH	Fatal Injury Rate Excluding Disaster Fatalities Per Million Man-Hours FRMHND
1950	9723	57.4236	73.9688	165	0	0.974482	0.974482
1951	10518	56.6626	70.0337	182	33	0.980470	0.802693
1952	9243	60.2796	71.2073	153	0	0.997812	0.997812
1953	6944	56.4608	57.5140	99	0	0.804957	0.804957
1954	5395	59.5245	53.1100	113	16	1.24676	1.07023
1955	6620	61.3319	53.7618	111	0	1.02837	1.02837
1956	5194	46.0564	38.7720	129	0	1.14387	1.14387
1957	6397	58.8193	46.3410	156	53	1.43439	0.947068
1958	5478	71.5007	51.1675	118	42	1.54018	0.991979
1959	4155	58.5565	38.0213	73	0	1.02879	1.02879
1960	4239	62.5980	38.2704	102	18	1.50625	1.24044
1961	3994	66.8642	39.6409	70	0	1.17188	1.17188
1962	4000	68.0875	38.0749	58	0	0.987269	0.987269
1963	4046	62.6577	34.4062	114	22	1.76544	1.42474
1964	4110	62.1751	32.3628	74	0	1.11945	1.11945
1965	4304	62.7774	32.1535	89	7	1.29814	1.19604
1966	4091	61.7324	30.8802	74	7	1.11664	1.01102
1967	3976	60.0098	29.6694	55	0	0.830115	0.830115
1968	3653	57.4418	28.6023	142	78	2.23288	1.00637
1969	3597	58.8078	30.9259	55	0	0.899202	0.899202
1970	4367	64.0851	37.9790	60	0	0.880492	0.880492
1971	4362	63.6540	47.4357	34	0	0.496157	0.496157
1972	4799	65.8084	47.7243	45	14	0.617083	0.425101
1973	4357	61.0752	37.2243	38	0	0.532673	0.532673
1974	3873	60.1053	47.1556	30	0	0.465572	0.465572
1975	4704	57.1220	53.2393	31	0	0.376442	0.376442

Table 66 (Continued)

Year	Fatal Injury Rate Per Million Tons FRPR	Fatal Injury Rate Excluding Disaster Fatalities Per Million Tons FRPRND	Total Production TPROD (millions of short tons)	Number of Man-Days Worked MNDY (millions of man-days)	Weighted-Average Seam Thickness ST (inches)	Percent of Coal Loaded Mechanically PMECH	Weighted-Average Employment AEMPL	Average Production AP (short tons)	MACT
1950	1.25526	1.25526	131.447	12.1651	60.58	74.2	59	133044	0.0
1951	1.21184	0.992111	150.185	23.2032	60.15	77.0	74	175655	0.0
1952	1.17870	1.17870	129.804	19.1669	59.54	80.3	66	164309	0.0
1953	0.819973	0.819973	120.736	15.3735	59.86	83.8	65	187187	0.0
1954	1.11241	0.954898	101.582	11.3294	61.11	88.5	50	165173	0.0
1955	0.901445	0.901445	123.136	13.4922	60.51	90.0	58	191800	0.0
1956	0.962955	0.962955	133.963	14.0968	61.86	89.0	59	205780	0.0
1957	1.13009	0.746151	138.042	13.5946	61.40	89.6	45	167526	0.0
1958	1.10218	0.709882	107.060	9.57682	61.00	90.8	35	141054	0.0
1959	0.668004	0.668004	109.281	8.86965	62.13	92.1	28	125178	0.0
1960	0.920874	0.758367	110.764	8.46473	61.06	91.5	20	97418	0.0
1961	0.694758	0.694758	100.754	7.46663	61.33	91.5	19	91429	0.0
1962	0.552086	0.552086	105.056	7.34349	60.36	91.6	16	85620	0.0
1963	0.969428	0.782346	117.595	8.07164	60.88	91.8	16	82639	0.0
1964	0.582687	0.582687	126.998	8.26295	61.59	92.7	17	94633	0.0
1965	0.664886	0.612591	133.858	8.56996	61.15	94.2	18	101484	0.0
1966	0.558577	0.505739	132.479	8.28374	61.64	96.0	18	105899	0.0
1967	0.410417	0.410417	134.010	8.28199	62.04	97.9	22	127386	0.0
1968	1.11183	0.501108	127.717	7.94936	62.62	97.8	24	138974	0.0
1969	0.472874	0.472874	116.310	7.64567	62.70	98.3	25	136835	0.0
1970	0.521810	0.521810	114.984	8.51797	63.34	98.3	32	157946	5.15924
1971	0.369742	0.369742	91.9561	8.56583	63.73	98.4	37	145500	10.46780
1972	0.447509	0.308284	100.557	9.11547	62.98	99.1	45	180209	29.23300
1973	0.324655	0.324655	117.047	8.91728	67.61	99.5	47	225091	42.68330
1974	0.365264	0.365264	82.1324	8.05461	62.83	99.9	37	138503	52.09470
1975	0.350854	0.350854	88.3558	10.2938	62.79	100.0	39	123230	39.14790

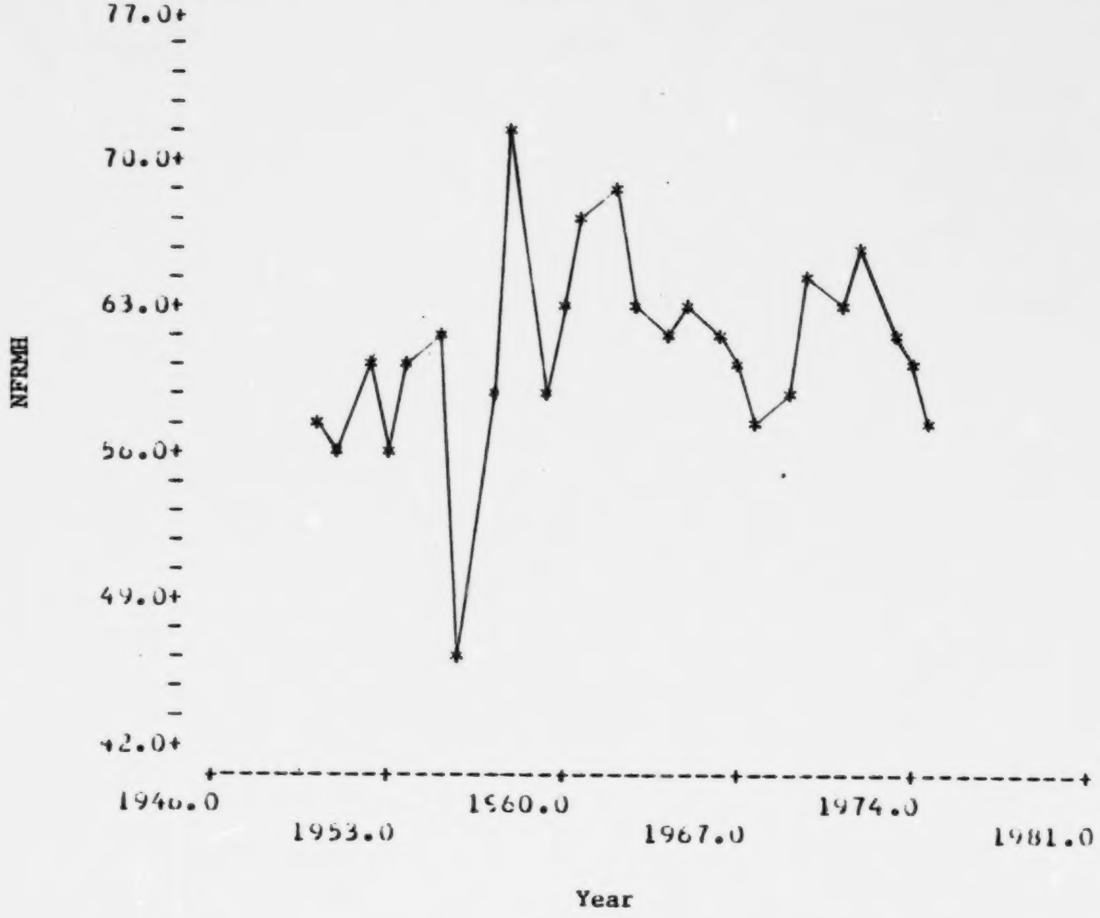


Figure 119. Trend of Nonfatal Injury Rate Per Million Man-Hours: West Virginia (1950 Through 1975)

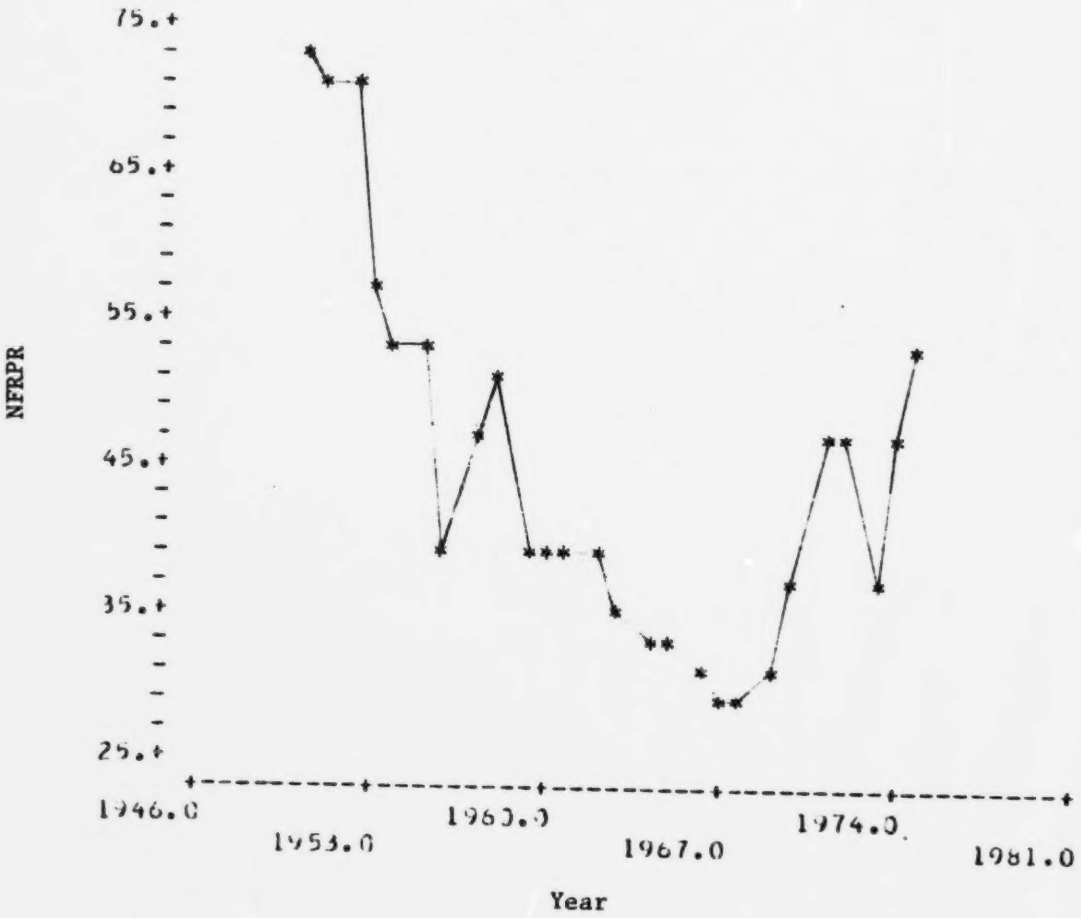


Figure 120. Trend of Nonfatal Injury Rate Per Million Tons: West Virginia (1950 Through 1975)

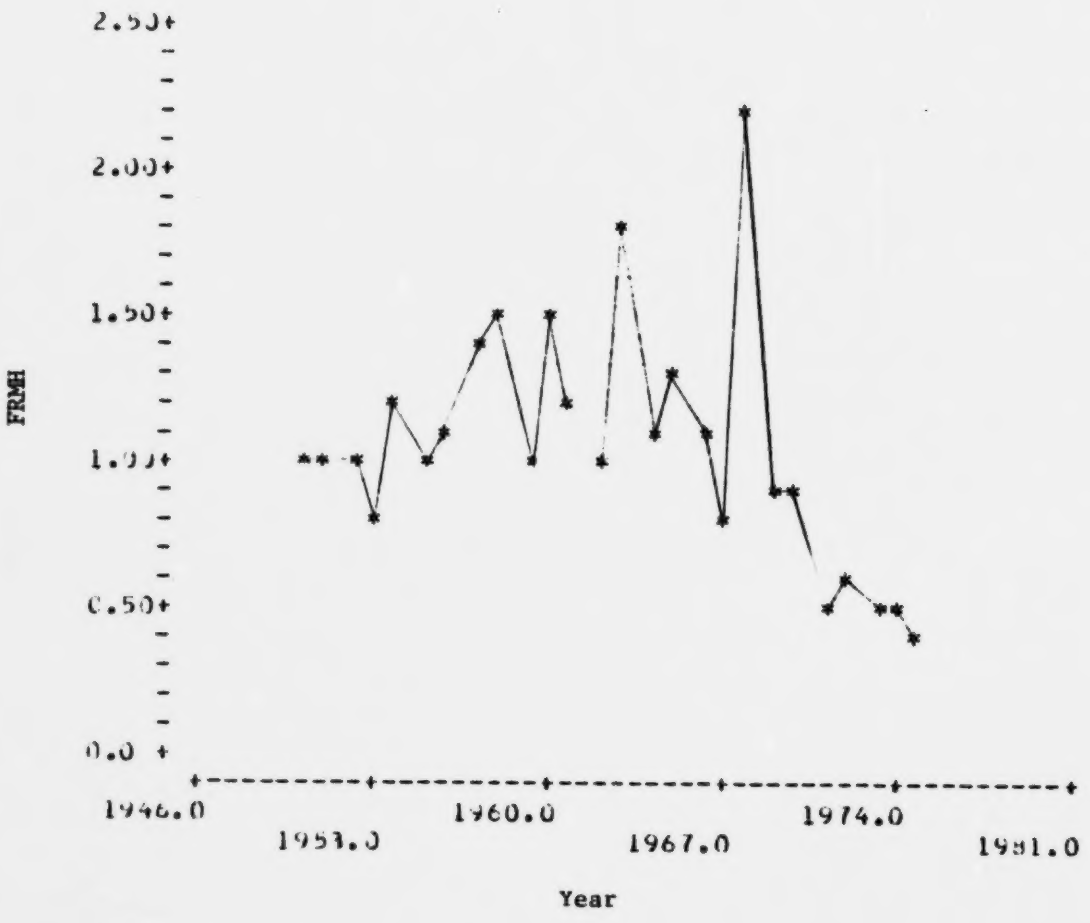


Figure 121. Trend of Fatal Injury Rate Per Million Man-Hours: West Virginia (1950 Through 1975)

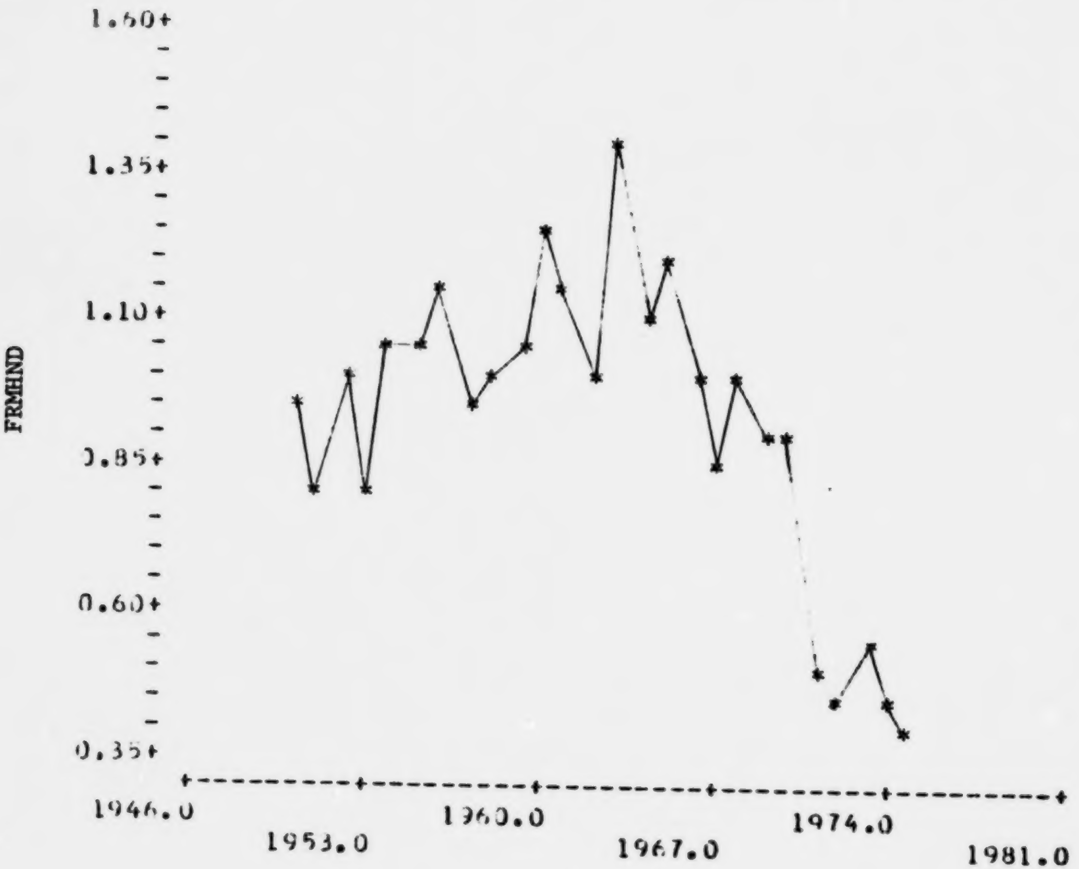


Figure 122. Trend of Fatal Injury Rate Excluding Disasters Per Million Man-Hours: West Virginia (1950 Through 1975)

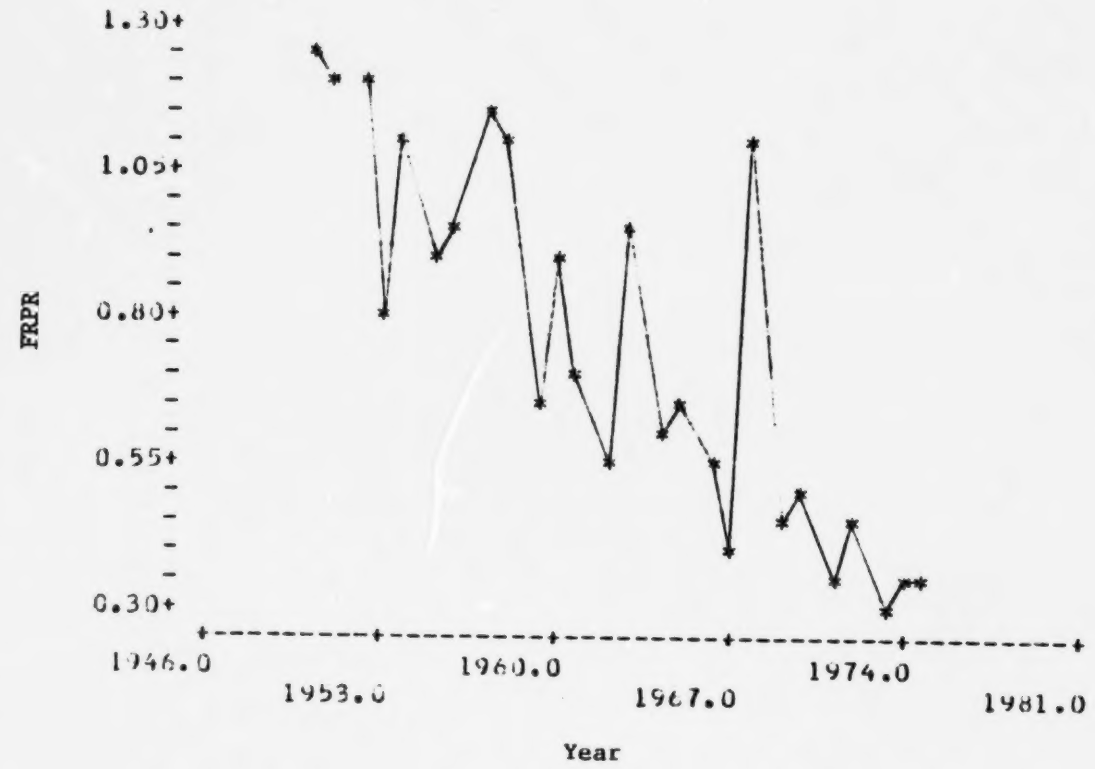


Figure 123. Trend of Fatal Injury Rate Per Million Tons: West Virginia (1950 Through 1975)

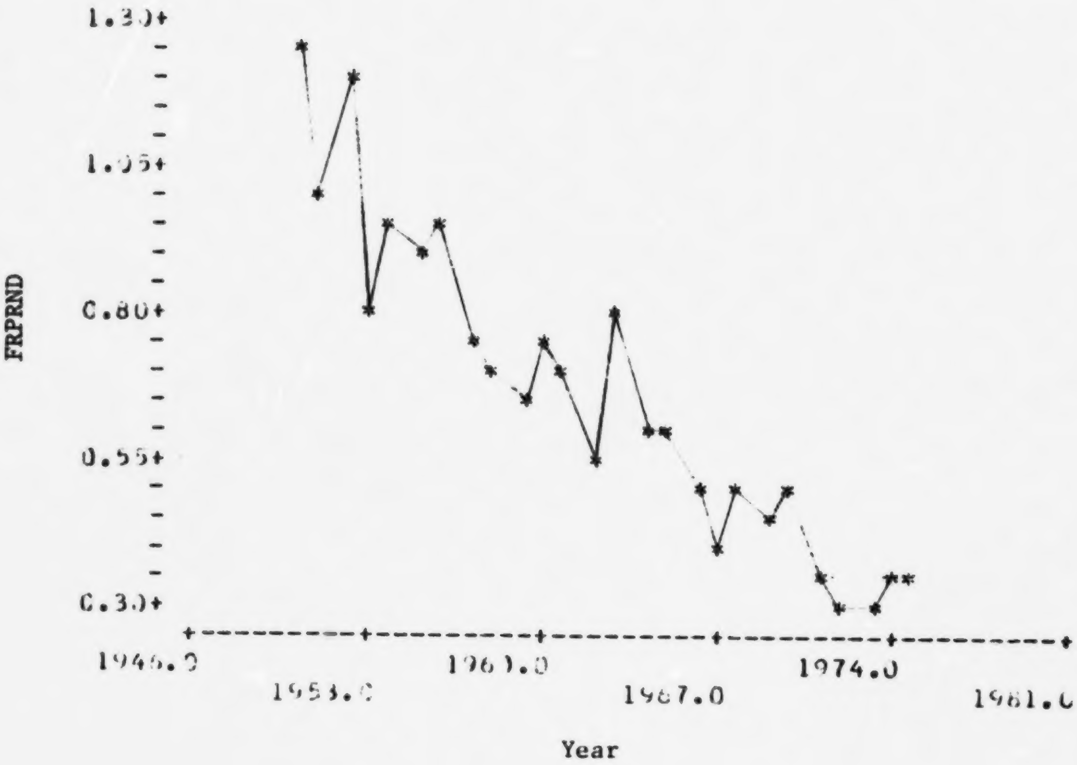


Figure 124. Trend of Fatal Injury Rate Excluding Disasters Per Million Tons: West Virginia (1950 Through 1975)

(2) $NFRPR_t = 66.74 - 2.050\ X_1 + 7.25\ X_2\ (X_1-20)$

$(2.84)\ (0.226)****(1.01)****$

$R^2 = 0.78$

F-statistic (2,23) = 41.76

Standard error of the regression = 6.26

****Significant at the 99.0 percent confidence level.

Piecewise regression using a join point of 1968 gives better results:

(2a) $NFRPR_t = 68.25 - 2.258\ X_1 + 6.643\ X_2\ (X_1-19)$

$(2.55)\ (0.211)****(0.770)****$

$R^2 = 0.834$

F-statistic (2,23) = 57.86

Standard error of the regression = 5.48

****Significant at the 99.0 percent confidence level.

Fatal injury rates per million man-hours including disaster fatalities (Figure 121) show a generally level to slightly upward trend through the late 1960s to 1970 with outliers for disaster years (especially in 1968 with 1978 disaster fatalities). Piecewise regression reveals a significant break in trend in 1969 (99.0 percent confidence level) from a positive to a negative slope:

(3) $FRMH_t = 20.0 + 0.0108\ X_1 - 0.1919\ X_2\ (X_1-1969)$

$(23.0)\ (0.0117)\quad (0.0522)****$

$R^2 = 0.447$

F-statistic (2,23) = 9.30

Standard error of the regression = 0.324

****Significant at the 99.0 percent confidence level.

The fatal injury rate per million man-hours for non-disaster fatalities is plotted versus time in Figure 122. A break in trend in 1969 from increasing to decreasing is significant at the 99.0 percent confidence level. The results of the piecewise regression are as follows.

$$\text{(4)}\ FRMHND_t = -1.61 + 0.00134\ X_1 - 0.1311\ X_2\ (X_1-1969)$$
$$(11.3)\quad (0.00578)\quad (0.0257)^{****}$$

$R^2 = 0.671$

F-statistic (2,23) = 23.43

Standard error of the regression = 0.160

****Significant at the 99.0 percent confidence level.

Better results are obtained, however, using a join point of 1965. The results are:

$$\text{(4a)}\ FRMHND_t = 0.8890 + 0.01863\ X_1 - 0.1055\ X_2\ (X_1-1965)$$
$$(0.0610)\quad (0.00575)^{****}\quad (0.0134)^{****}$$

$R^2 = 0.81$

F-statistic (2,23) = 49.07

Standard error of the regression = 0.121

**** Significant at the 99.0 percent confidence level.

The trend for fatality rates including disaster fatalities per million tons produced (Figure 123) is for decreasing rates through time with outliers in disaster years (again, especially in 1968). There is no statistical evidence for a break in trend in 1969:

$$\text{(5)}\ FRPR_t = 1.2095 - 0.03316\ X_1 - 0.0036\ X_2\ (X_1-20)$$
$$(0.0793)\quad (0.0063\ X_2)^{****}(0.0281)$$

$R^2 = 0.704$

F-statistic (2,23) = 27.36

Standard error of the regression = 0.174

****Significant at the 99.0 percent confidence level.

Fatality rates per million tons produced for non-disaster fatalities are shown plotted versus time in Figure 124. Again the trend is downward. The results of the piecewise regression are:

$$(6)\ \begin{array}{llll} FRPRND_t = & 1.1244 & - 0.03513\ X_1 & + 0.0225\ X_2\ (X_1 - 20) \\ & (0.0415) & (0.00331)^{****} & (0.0147) \end{array}$$

$R^2 = 0.885$

F-statistic (2,23) = 88.89

Standard error of the regression = 0.0913

****Significant at the 99.0 percent confidence level.

There is no statistically significant break in trend in 1969.

The trends for weighted-average seam thickness and average production (Figure 3 and 5) have been described in the section on West Virginia in Chapter III. Percent of coal loaded mechanically (Figure 125) increases from around 74 percent in 1950 to around 98 percent in 1967, then rises slowly with a value in 1975 of 100 percent. Weighted-average employment (Figure 126) trends downward through 1963 then upward through 1975, dropping slightly in 1974 and 1975.

Results of Regressions for 1950 Through 1975

Results for appropriate regressions for the six injury rates--NFRMH, NFRPR, FRMH, FRMHND, FRPR, and FRPRND--are shown in Tables 67 and 68. The correlation matrices are shown in Tables 69 and 70. The highest pairwise correlation is between ST and PMECH (0.82). No regression has the

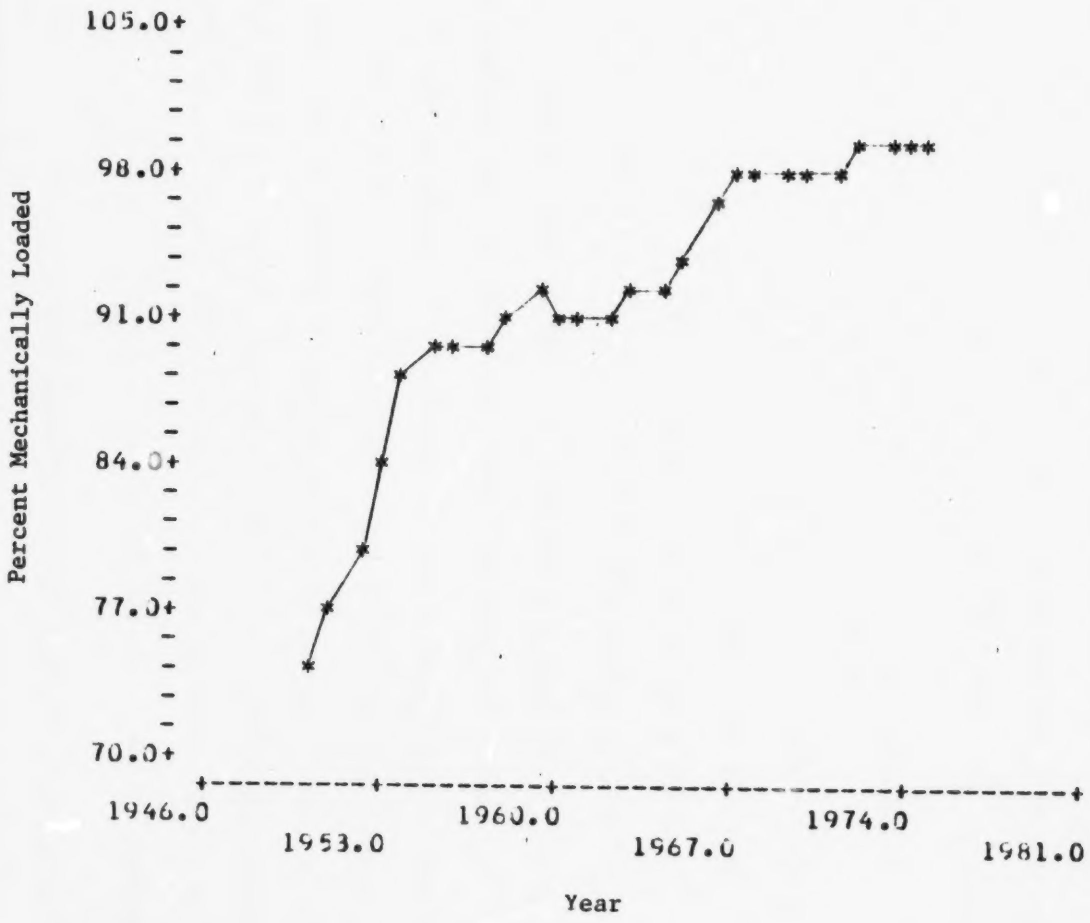


Figure 125. Trend of Percent Mechanically Loaded: West Virginia (1950 Through 1975)

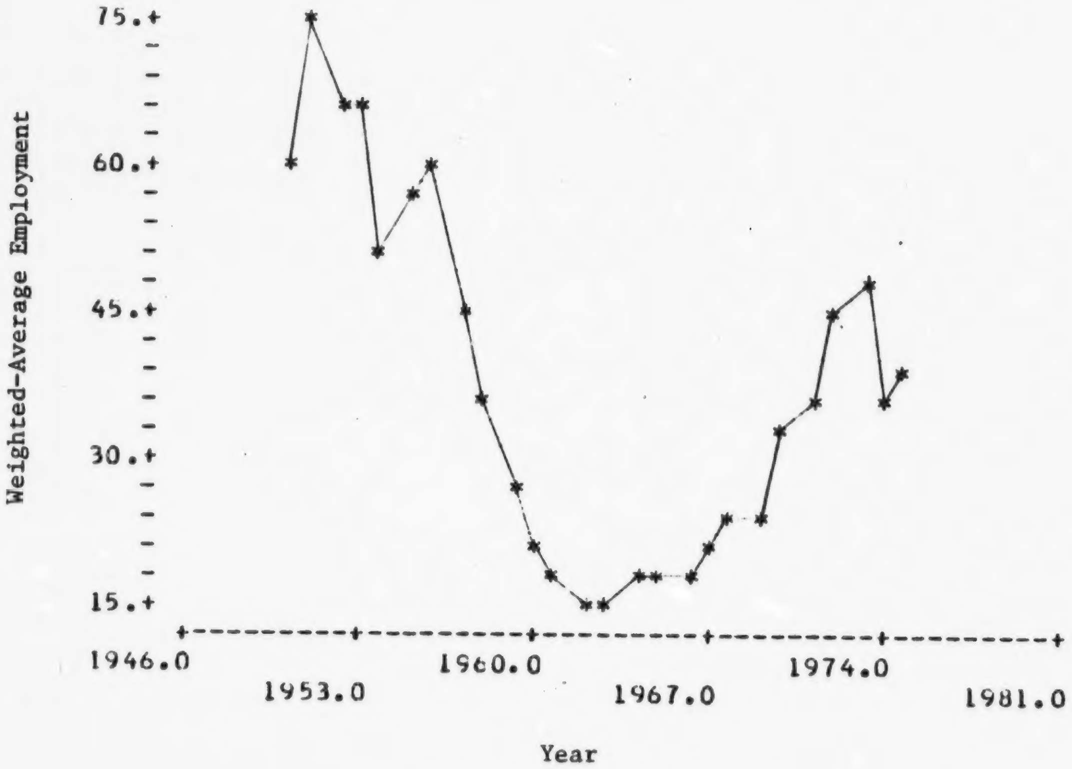


Figure 126. Trend of Weighted-Average Employment: West Virginia (1950 Through 1975)

Table 67

Results of Regressions for Injury Model: West Virginia
(1950 Through 1975)

Equation Dependent Variable	Constant[‡]	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-correlation (Durbin-Watson statistic)	F-Statistic
7(OLS) NFRMH	144.344 (72.9375)	-1.750 (1.453)	0.338 (0.241)	-49.010 (27.181) ##		0.012 (0.070)	0.30	4.37	None(1.69)	$2.20_{(4,21)}$[‡‡]
8(OLS) NFRPR	126.869 (83.731)	0.480 (1.691)	-1.348 (0.365) #####		0.272 (0.091) ****	0.355 (0.095) ****	0.87	5.07	None(2.07)	$35.27_{(4,21)}$
9(OLS) FRMH	4.724 (5.719)	-0.080 (0.114)	0.017 (0.019)	-1.218 (2.131)		-0.017 (0.006) #####	0.44	0.34	None(2.60)	$4.08_{(4,21)}$
10(OLS) FRMHND	5.577 (2.551)	0.081 (0.051) #	-0.007 (0.008)	1.749 (0.951) ##		-0.012 (0.002) #####	0.73	0.15	None(2.15)	$13.86_{(4,21)}$
11(OLS) FRPR	3.542 (3.146)	-0.012 (0.064)	-0.023 (0.014) #		0.003 (0.003)	-0.006 (0.004) #	0.68	0.19	None(2.53)	$11.00_{(4,21)}$
12(OLS) FRPRND	3.961 (1.615)	-0.015 (0.033)	-0.026 (0.007) #####		0.002 (0.002)	-0.003 (0.002) #	0.88	0.10	None(2.52)	$38.43_{(4,21)}$

[‡] Standard deviations of coefficients are given in parentheses on all tables.

[‡‡] The equation is not significant at the 95.0 percent confidence level or greater.

Significance Levels:
- **** Significant at the 99.0 percent confidence level (two-tail test)
- # Significant at the 90.0 percent confidence level (one-tail test)
- ## Significant at the 95.0 percent confidence level (one-tail test)
- ##### Significant at the 99.5 percent confidence level (one-tail test)

Table 68

Ninety-Five Percent Confidence Intervals for Coefficients in West Virginia Regressions of Injury Model (1950 Through 1975)

Equation Dependent Variable	ST		PMECH		AP		AEMPL		MACT	
7(OLS) NFRMH	-4.77	1.27	-0.16	0.84	-105.55	7.53			-0.13	0.16
8(OLS) NFRPR	-3.04	4.00	-2.11	-0.59			0.08	0.46	0.16	0.55
9(OLS) FRMH	-0.32	0.16	-0.02	0.06	-5.65	3.21			-0.03	-0.005
10(OLS) FRMHND	-0.03	0.19	-0.02	0.01	-0.23	3.73			-0.02	-0.01
11(OLS) FRPR	-0.15	0.12	-0.05	0.01			-0.00	0.01	-0.01	0.002
12(OLS) FRPRND	-0.08	0.05	-0.04	-0.01			-0.00	0.00	-0.01	0.001

Table 69

Pairwise Correlation Matrix for ST, PMECH, AP, and MACT: West Virginia (1950 Through 1975)

	ST	PMECH	AP	MACT
ST	1.0001	0.81751	0.026270	0.52174
PMECH	0.81751	1.0000	-0.19145	0.50184
AP	0.026270	-0.19145	1.0000	0.17476
MACT	0.52174	0.50184	0.17476	1.0000

Table 70

Pairwise Correlation Matrix for ST, PMECH, AEMPL, and MACT: West Virginia (1950 Through 1975)

	ST	PMECH	AEMPL	MACT
ST	1.0001	0.81751	-0.33841	0.52174
PMECH	0.81751	1.0000	-0.60904	0.50184
AEMPL	-0.33841	-0.60904	1.0000	0.094982
MACT	0.52174	0.50184	0.094982	1.0000

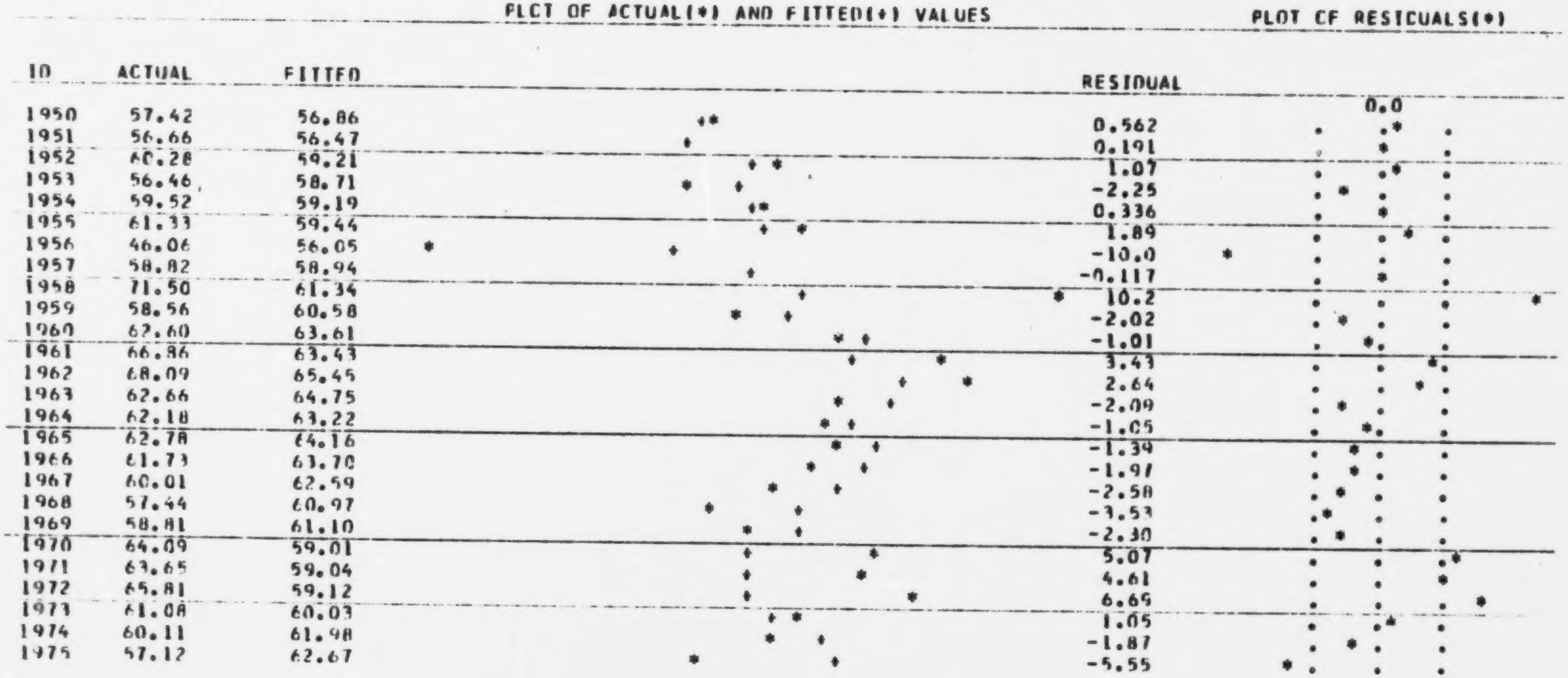
problem of autocorrelation. Appropriate plots are presented in Figures 127 through 132. There is no evidence of heteroskedasticity in any of the residuals plots.

The regression of NFRMH produces the least satisfactory results, since the equation is not significant at the 95.0 percent confidence level or greater, and the percent of variance explained is only 30.0. The results of the regression for NFRPR indicate that the coefficients of all of the independent variables except ST are significant, with that of MACT being positive. For all of the fatal injury rates, the coefficient of MACT is negative and significant. The coefficients of ST are negative, as expected, in the equations for NFRMH, FRMH, FRPR, and FRPRND. In the regressions of NFRPR and FRMHND, however, the coefficients of ST are positive but not significant. The coefficients of PMECH are negative, as expected, and significant in the equations for NFRPR, FRPR, and FRPRND. In the equations for NFRMH and FRMH, the coefficients are positive but not significant. The coefficients of AP are negative, as expected, and significant in the equations for NFRMH and FRMHND. The coefficients of AEMPL are positive in all three equations, but significant in only one (NFRPR).

Results of Regressions for 1950 Through 1969 and Predictions of Productivity

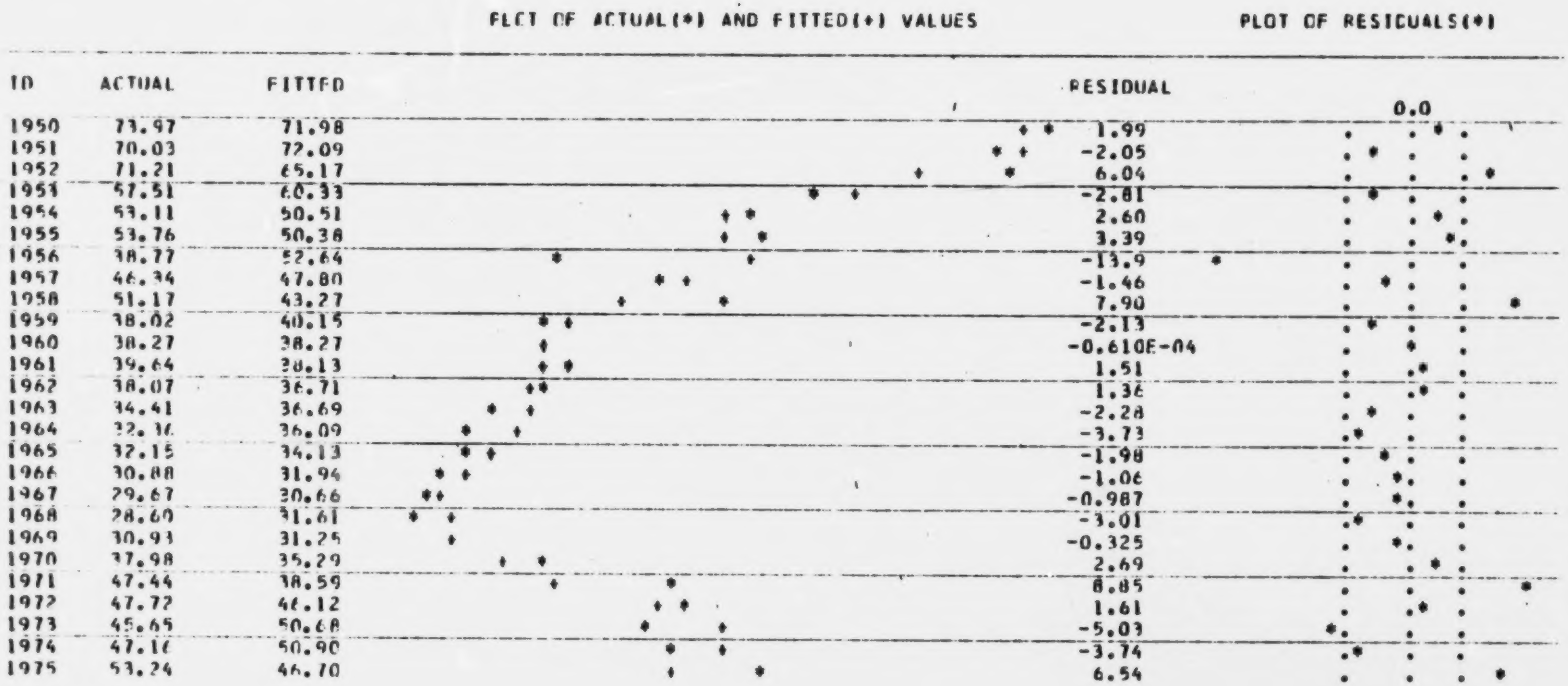
This section derives predictions of injury rate levels that might have been obtained in 1970 through 1975 if the Coal Mine Health and Safety Act had not been passed.

It is possible that the legislation could have indirect effects on injury rates by affecting the other independent variables in some way. If so, this could affect the predictions. Reexamining trends, those of AP and ST are discussed in the West Virginia section of Chapter III. The



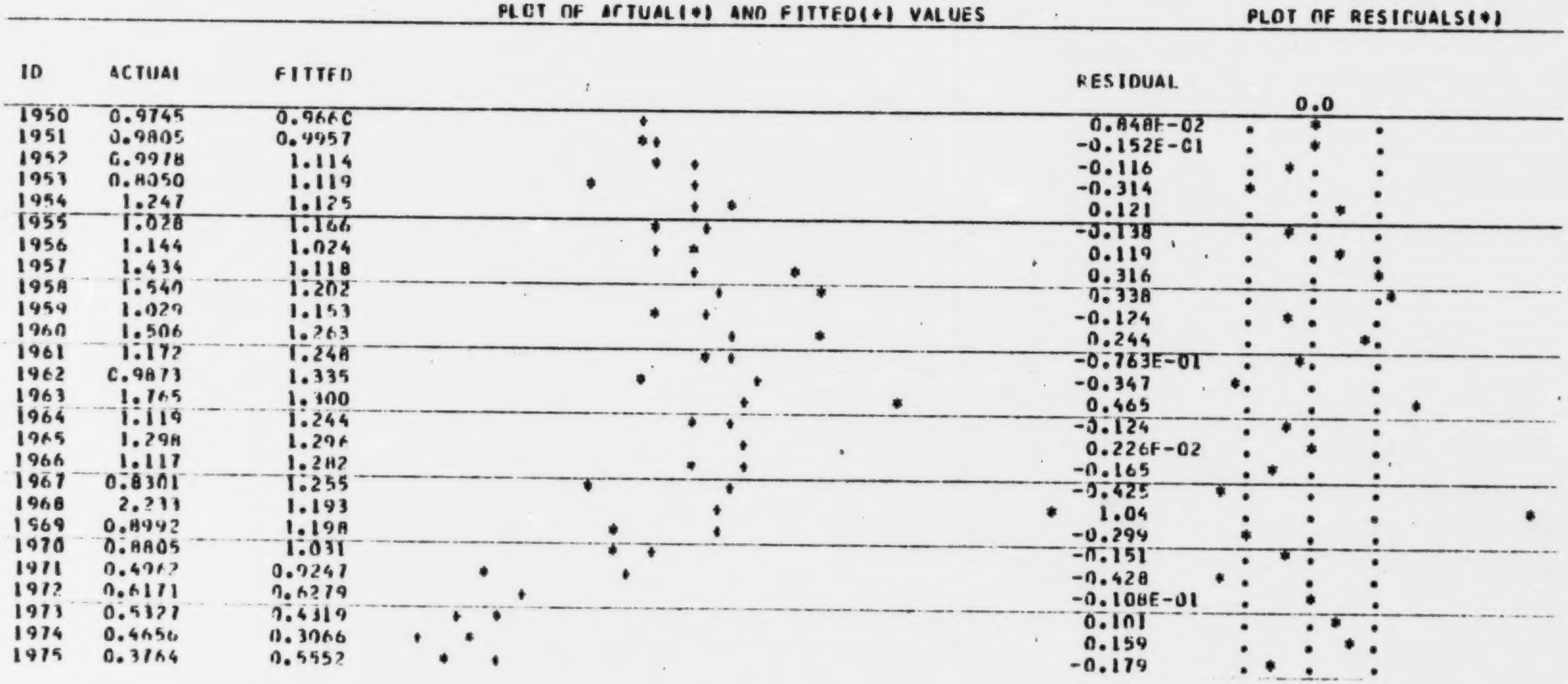
```
                    PLCT OF ACTUAL(*) AND FITTED(+) VALUES                PLOT CF RESICUALS(*)

ID     ACTUAL     FITTED                                      RESIDUAL

1950   57.42      56.86                                        0.562
1951   56.66      56.47                                        0.191
1952   60.28      59.21                                        1.07
1953   56.46      58.71                                       -2.25
1954   59.52      59.19                                        0.336
1955   61.33      59.44                                        1.89
1956   46.06      56.05                                       -10.0
1957   58.82      58.94                                       -0.117
1958   71.50      61.34                                        10.2
1959   58.56      60.58                                       -2.02
1960   62.60      63.61                                       -1.01
1961   66.86      63.43                                        3.43
1962   68.09      65.45                                        2.64
1963   62.66      64.75                                       -2.09
1964   62.18      63.22                                       -1.05
1965   62.78      64.16                                       -1.39
1966   61.73      63.70                                       -1.97
1967   60.01      62.59                                       -2.58
1968   57.44      60.97                                       -3.53
1969   58.81      61.10                                       -2.30
1970   64.09      59.01                                        5.07
1971   63.65      59.04                                        4.61
1972   65.81      59.12                                        6.69
1973   61.08      60.03                                        1.05
1974   60.11      61.98                                       -1.87
1975   57.12      62.67                                       -5.55
```

Figure 127. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1950 Through 1975: West Virginia (OLS)



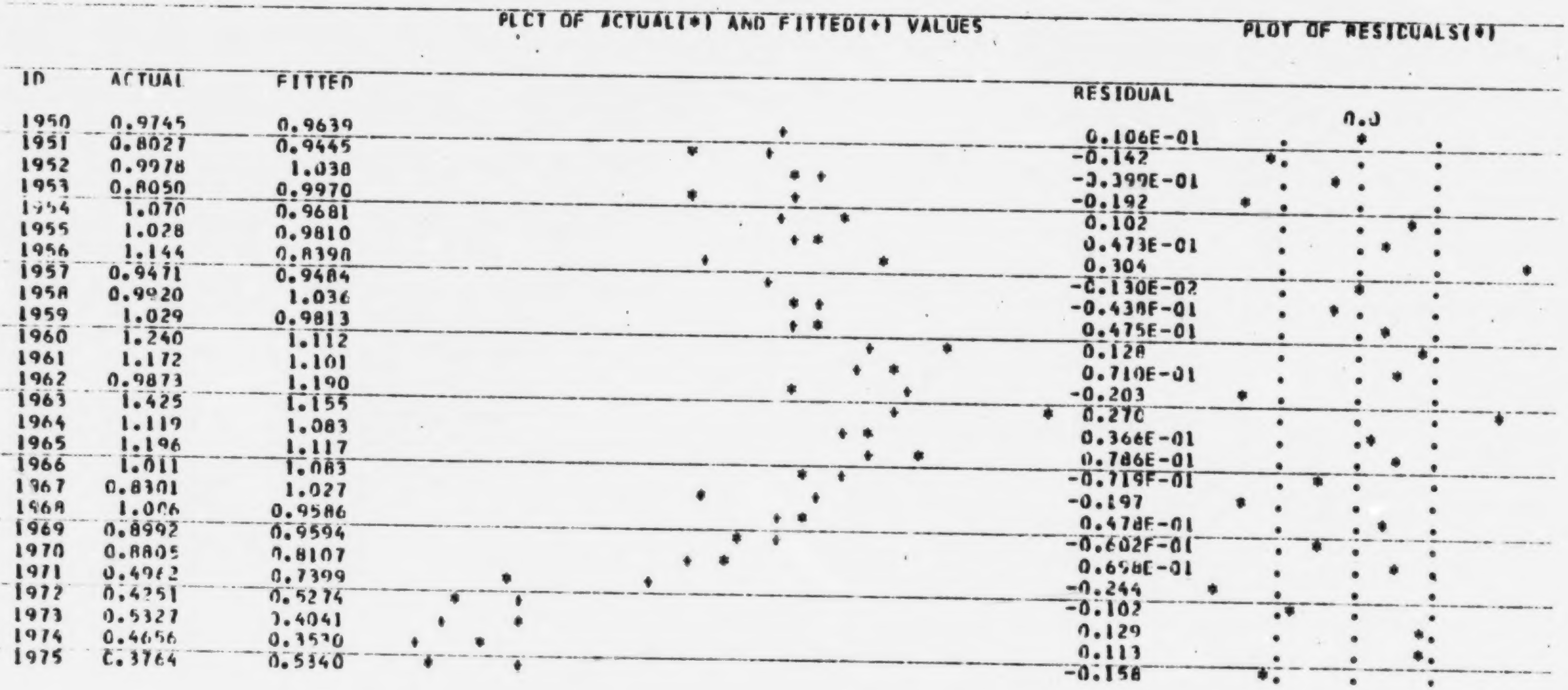
ID	ACTUAL	FITTED	RESIDUAL
1950	73.97	71.98	1.99
1951	70.03	72.09	-2.05
1952	71.21	65.17	6.04
1953	57.51	60.33	-2.81
1954	53.11	50.51	2.60
1955	53.76	50.38	3.39
1956	38.77	52.64	-13.9
1957	46.34	47.80	-1.46
1958	51.17	43.27	7.90
1959	38.02	40.15	-2.13
1960	38.27	38.27	-0.610E-04
1961	39.64	38.13	1.51
1962	38.07	36.71	1.36
1963	34.41	36.69	-2.28
1964	32.36	36.09	-3.73
1965	32.15	34.13	-1.98
1966	30.88	31.94	-1.06
1967	29.67	30.66	-0.987
1968	28.60	31.61	-3.01
1969	30.93	31.25	-0.325
1970	37.98	35.29	2.69
1971	47.44	38.59	8.85
1972	47.72	46.12	1.61
1973	45.65	50.68	-5.03
1974	47.16	50.90	-3.74
1975	53.24	46.70	6.54

Figure 128. Plots for Nonfatal Injury Rate Per Million Tons, 1950 Through 1975: West Virginia (OLS)



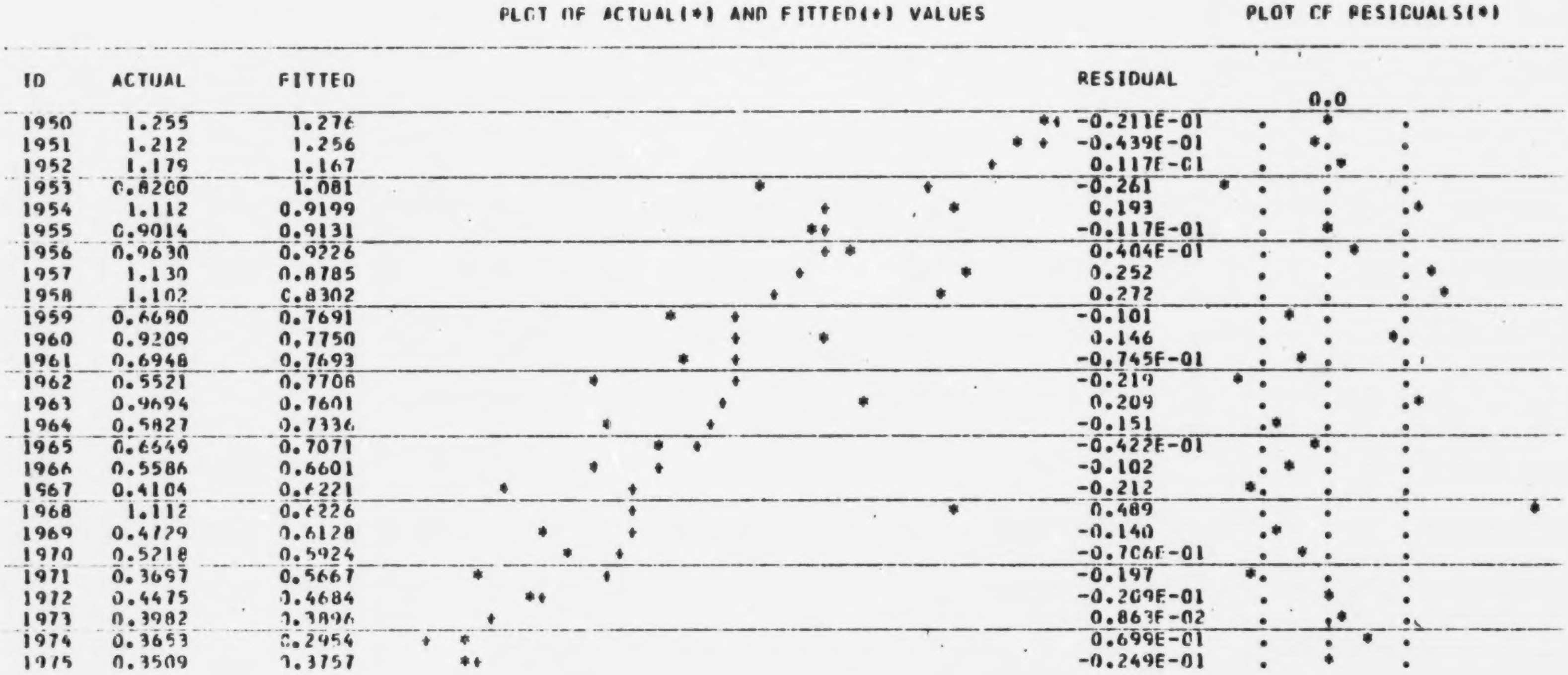
```
ID      ACTUAL      FITTED        RESIDUAL
1950    0.9745      0.9660        0.848E-02
1951    0.9805      0.9957       -0.152E-01
1952    0.9978       1.114       -0.116
1953    0.8050       1.119       -0.314
1954     1.247       1.125        0.121
1955     1.028       1.166       -0.138
1956     1.144       1.024        0.119
1957     1.434       1.118        0.316
1958     1.540       1.202        0.338
1959     1.029       1.153       -0.124
1960     1.506       1.263        0.244
1961     1.172       1.248       -0.763E-01
1962    0.9873       1.335       -0.347
1963     1.765       1.300        0.465
1964     1.119       1.244       -0.124
1965     1.298       1.296        0.226E-02
1966     1.117       1.282       -0.165
1967    0.8301       1.255       -0.425
1968     2.233       1.193        1.04
1969    0.8992       1.198       -0.299
1970    0.8805       1.031       -0.151
1971    0.4962      0.9247       -0.428
1972    0.6171      0.6279       -0.108E-01
1973    0.5327      0.4319        0.101
1974    0.4656      0.3066        0.159
1975    0.3764      0.5552       -0.179
```

Figure 129. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1975: West Virginia (OLS)



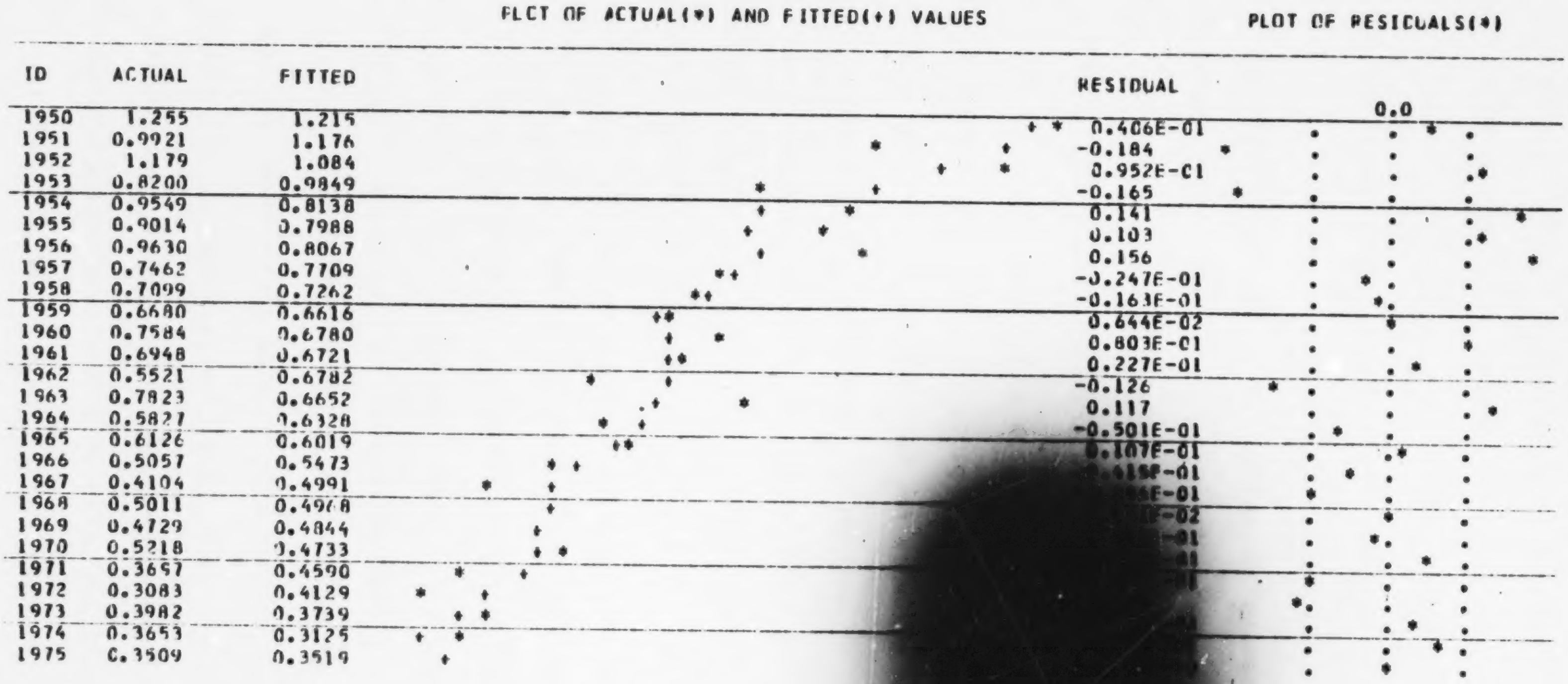
```
                                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID     ACTUAL       FITTED
                                                                      RESIDUAL
1950   0.9745       0.9639                                                                   0.0
1951   0.8027       0.9445                                             0.106E-01
1952   0.9978       1.038                                              -0.142
1953   0.8050       0.9970                                             -0.399E-01
1954   1.070        0.9681                                             -0.192
1955   1.028        0.9810                                             0.102
1956   1.144        0.8390                                             0.473E-01
1957   0.9471       0.9484                                             0.304
1958   0.9920       1.036                                              -0.130E-02
1959   1.029        0.9813                                             -0.438E-01
1960   1.240        1.112                                              0.475E-01
1961   1.172        1.101                                              0.128
1962   0.9873       1.190                                              0.710E-01
1963   1.425        1.155                                              -0.203
1964   1.119        1.083                                              0.270
1965   1.196        1.117                                              0.366E-01
1966   1.011        1.083                                              0.786E-01
1967   0.8301       1.027                                              -0.719E-01
1968   1.006        0.9586                                             -0.197
1969   0.8992       0.9594                                             0.478E-01
1970   0.8805       0.8107                                             -0.602E-01
1971   0.4962       0.7399                                             0.658E-01
1972   0.4251       0.5274                                             -0.244
1973   0.5327       0.4041                                             -0.102
1974   0.4656       0.3530                                             0.129
1975   0.3764       0.5340                                             0.113
                                                                       -0.158
```

Figure 130. Plots for Fatal Injury Rate Excluding Disasters Per Million Man-Hours, 1950 Through 1975: West Virginia (OLS)



```
                                   PLOT OF ACTUAL(*) AND FITTED(+) VALUES                  PLOT OF RESIDUALS(*)
-----------------------------------------------------------------------------------------------------------------
ID     ACTUAL      FITTED                                                     RESIDUAL
                                                                                                0.0
-----------------------------------------------------------------------------------------------------------------
1950    1.255       1.276                                                   *+ -0.211E-01   .    *     .
1951    1.212       1.256                                                 * +  -0.439E-01   .   *.     .
1952    1.179       1.167                                               +       0.117E-01   .    .*    .
-----------------------------------------------------------------------------------------------------------------
1953   0.8200       1.081                              *           +           -0.261    *  .    .     .
1954    1.112      0.9199                                   +        *          0.193       .    .     .*
1955   0.9014      0.9131                                  *+                  -0.117E-01   .    *     .
-----------------------------------------------------------------------------------------------------------------
1956   0.9630      0.9226                                   +*                  0.404E-01   .    . *   .
1957    1.130      0.8785                                 +           *         0.252       .    .     . *
1958    1.102      0.8302                               +           *           0.272       .    .     .  *
-----------------------------------------------------------------------------------------------------------------
1959   0.6690      0.7691                       *    +                         -0.101       . *  .     .
1960   0.9209      0.7750                            +      *                   0.146       .    .    *.
1961   0.6948      0.7693                        *   +                         -0.745E-01   .  * .     .
-----------------------------------------------------------------------------------------------------------------
1962   0.5521      0.7708                 *          +                         -0.219     * .    .     .
1963   0.9694      0.7601                           +          *                0.209       .    .     .*
1964   0.5827      0.7336                  *       +                           -0.151       .*   .     .
-----------------------------------------------------------------------------------------------------------------
1965   0.6649      0.7071                      *  +                            -0.422E-01   .   *.     .
1966   0.5586      0.6601                 *    +                               -0.102       . *  .     .
1967   0.4104      0.6221           *        +                                 -0.212      *.    .     .
-----------------------------------------------------------------------------------------------------------------
1968    1.112      0.6226                    +                       *          0.489       .    .     .        *
1969   0.4729      0.6128              *     +                                 -0.140       .*   .     .
1970   0.5218      0.5924               *   +                                  -0.706E-01   .  * .     .
-----------------------------------------------------------------------------------------------------------------
1971   0.3697      0.5667         *        +                                   -0.197      *.    .     .
1972   0.4475      0.4684             *+                                       -0.209E-01   .    *     .
1973   0.3982      0.3896          +                                            0.863E-02   .    .*    .
-----------------------------------------------------------------------------------------------------------------
1974   0.3653      0.2954     +  *                                              0.699E-01   .    .  *  .
1975   0.3509      0.3757         *+                                           -0.249E-01   .    *     .
```

Figure 131. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1975: West Virginia (OLS)



```
                                   PLOT OF ACTUAL(*) AND FITTED(+) VALUES            PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                          RESIDUAL
                                                                                          0.0
1950     1.255       1.215                                         0.406E-01
1951    0.9921       1.176                                        -0.184
1952     1.179       1.084                                         0.952E-C1
1953    0.8200      0.9849                                        -0.165
1954    0.9549      0.8138                                         0.141
1955    0.9014      0.7988                                         0.103
1956    0.9630      0.8067                                         0.156
1957    0.7462      0.7709                                        -0.247E-01
1958    0.7099      0.7262                                        -0.163E-01
1959    0.6680      0.6616                                         0.644E-02
1960    0.7584      0.6780                                         0.803E-01
1961    0.6948      0.6721                                         0.227E-01
1962    0.5521      0.6782                                        -0.126
1963    0.7823      0.6652                                         0.117
1964    0.5827      0.6328                                        -0.501E-01
1965    0.6126      0.6019                                         0.107E-01
1966    0.5057      0.5473                                         [illegible]
1967    0.4104      0.4991                                         [illegible]
1968    0.5011      0.4968                                         [illegible]
1969    0.4729      0.4844                                         [illegible]
1970    0.5218      0.4733                                         [illegible]
1971    0.3657      0.4590                                         [illegible]
1972    0.3083      0.4129                                         [illegible]
1973    0.3982      0.3739                                         [illegible]
1974    0.3653      0.3125                                         [illegible]
1975    C.3509      0.3519                                         [illegible]
```

Figure 132. Plots for Fatal Injury Rate Excluding Disasters [illegible] Through 1975: West Virginia (OLS)

percent of coal loaded mechanically (Figure 125) appears to be unaffected by the Mine Act, since the percent was reaching a "natural limit" before the Act was passed. Since the upward turn in weighted-average employment occurred in 1965, before the Act, the change in this variable seems not to be attributable to the Mine Act.

The results of regressions of the model using data through 1969 are shown in Tables 71 and 72. The correlation matrices are shown in Tables 73 and 74. The greatest pairwise correlation, -0.80, is between PMECH and AEMPL. Only the equation for FRMH has a problem of autocorrelation (negative); this is remedied using the Cochrane-Orcutt technique. Appropriate plots are presented in Figures 133 through 138. There is no evidence for heteroskedasticity. The coefficient of ST is significant only in the regression of NFRMH and is negative, as expected. The coefficients of PMECH are negative and significant, as expected, in the equations for NFRPR and FRPRND; the only other regression for which this coefficient is significant (NFRMH) produces an unexpectedly positive result. AP has a negative coefficient for all regressions but is significant only for NFRMH and FRMHND. The coefficient of AEMPL is positive but significant only in Equation 14 for NFRPR.

The regression equations were used to extrapolate possible injury rates in 1970 through 1975 in the absence of new federal legislation. These are reported in Table 75. With one exception, actual nonfatal injury rates are higher than predicted without the legislation. The differences are statistically significant in all years except 1973 through 1975 for NFRMH. For fatal injury rates per million man-hours, actual values are lower than predicted; these differences are statistically significant in all years except 1970. The predictions for

Table 71

Results of Regressions for Injury Model: West Virginia
(1950 Through 1969)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	R^2	S	Auto-correlation (Durbin-Watson statistic)	F-Statistic
13(OLS) NFRMH	287.341 (75.991)	-4.154 (1.456) ####	0.416 (0.205) *	-74.751 (23.818) #####		0.60	3.55	None(1.96)	$8.11_{(3,16)}$
14(OLS) NFRPR	312.066 (90.507)	-2.609 (1.708)	-1.290 (0.310) #####		0.219 (0.080) ***	0.93	4.21	None(2.14)	$70.68_{(3,16)}$
15(OLS) FRMH	-3.495 (7.604)	0.068 (0.146)	0.007 (0.021)	-1.199 (2.383)		0.13	0.35	-(2.95)	$0.77^{\ddagger}_{(3,16)}$
16(CORC) FRMH	-8.596 (5.496)	0.164 (0.110)	-0.001 (0.016)	-1.108 (1.365)		0.43	0.29	None(2.39)	$3.80_{(3,15)}$
17(OLS) FRMHND	2.069 (3.080)	-0.016 (0.059)	0.003 (0.008)	-1.904 (0.965) ##		0.26	0.14	None(2.02)	$1.84^{\ddagger}_{(3,16)}$
18(OLS) FRPR	-0.399 (4.415)	0.053 (0.833)	-0.024 (0.015)		0.004 (0.004)	0.51	0.21	None(2.85)	$5.65_{(3,16)}$
19(OLS) FRPRND	2.632 (2.229)	0.006 (0.042)	-0.026 (0.008) #####		0.003 (0.002)	0.83	0.10	None(2.68)	$26.53_{(3,16)}$

‡The equation is not significant at the 95.0 percent confidence level or greater.

Significance Levels:
- * Significant at the 90.0 percent confidence level (two-tail test)
- *** Significant at the 97.5 percent confidence level (two-tail test)
- ## Significant at the 95.0 percent confidence level (one-tail test)
- #### Significant at the 99.0 percent confidence level (one-tail test)
- ##### Significant at the 99.5 percent confidence level (one-tail test)

Table 72

Ninety-Five Percent Confidence Intervals for Coefficients in
West Virginia Regressions of Injury Model (1950 Through 1969)

Equation Dependent Variable	ST		PMECH		AP		AEMPL	
13(OLS) NFRMH	-7.24	-1.07	-0.02	0.85	-125.25	-24.26		
14(OLS) NFRPR	-6.23	1.01	-1.95	-0.63			0.05	0.39
15(OLS) FRMH	-0.24	0.38	-0.04	0.05	-6.25	3.85		
16(CORC) FRMH	-0.07	0.40	-0.04	0.03	-4.02	1.80		
17(OLS) FRMHND	-0.14	0.11	-0.01	0.02	-3.95	0.14		
18(OLS) FRPR	-1.71	1.82	-0.06	0.01			-0.00	0.01
19(OLS) FRPRND	-0.08	0.10	-0.04	-0.01			-0.00	0.01

Table 73

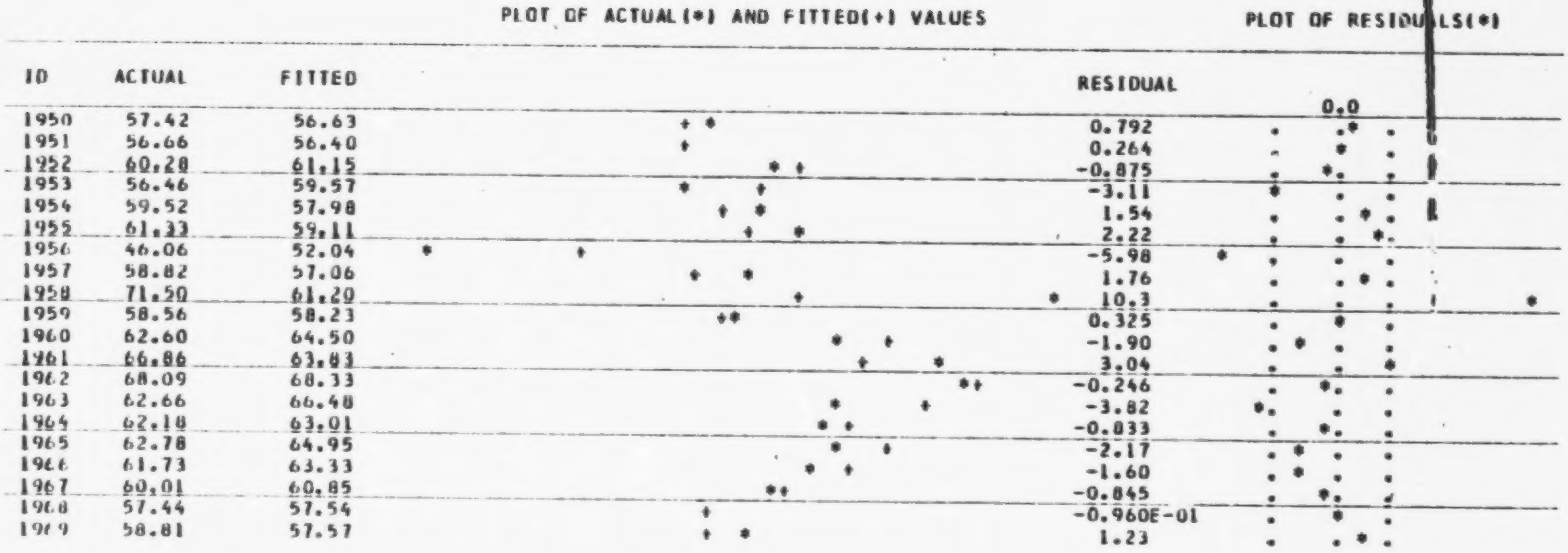
Pairwise Correlation Matrix for ST, PMECH, and AP: West Virginia (1950 Through 1969)

	ST	PMECH	AP
ST	1.0001	0.75062	-0.20131
PMECH	0.75062	1.0000	-0.41500
AP	-0.20131	-0.41500	1.0000

Table 74

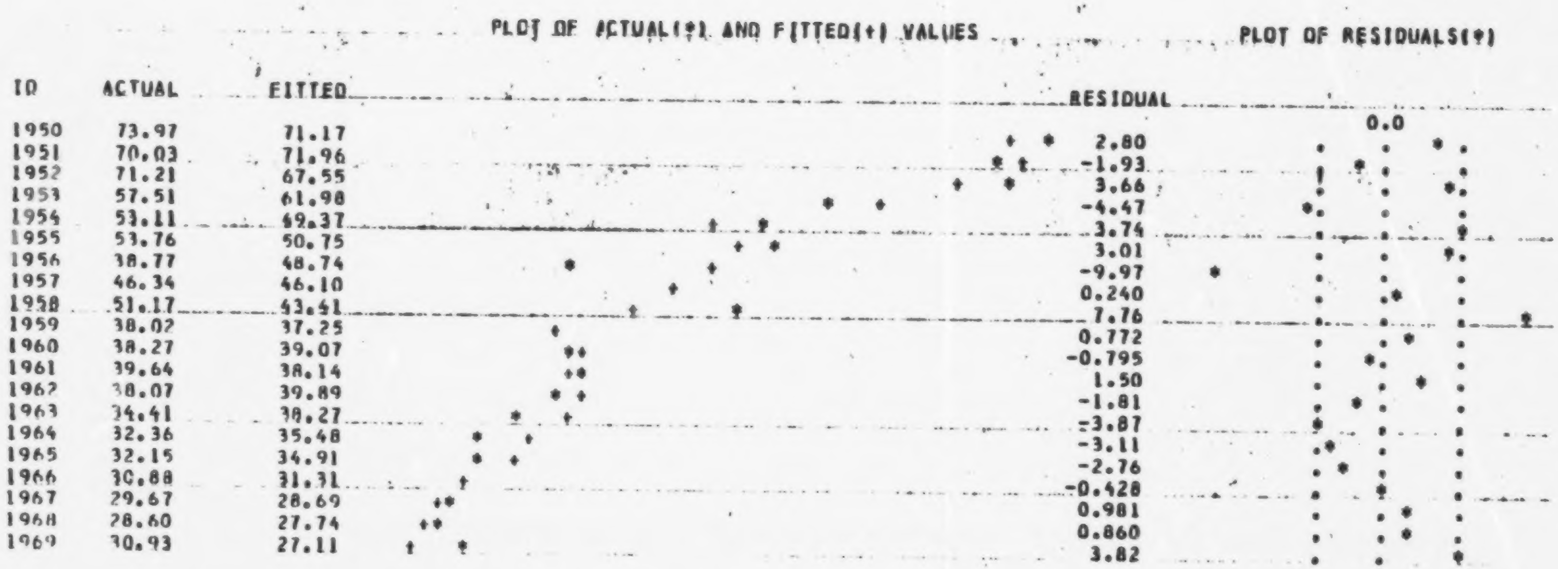
Pairwise Correlation Matrix for ST, PMECH, and AEMPL: West Virginia (1950 Through 1969)

	ST	PMECH	AEMPL
ST	1.0001	0.75062	-0.55816
PMECH	0.75062	1.0000	-0.80155
AEMPL	-0.55816	-0.80155	1.0000



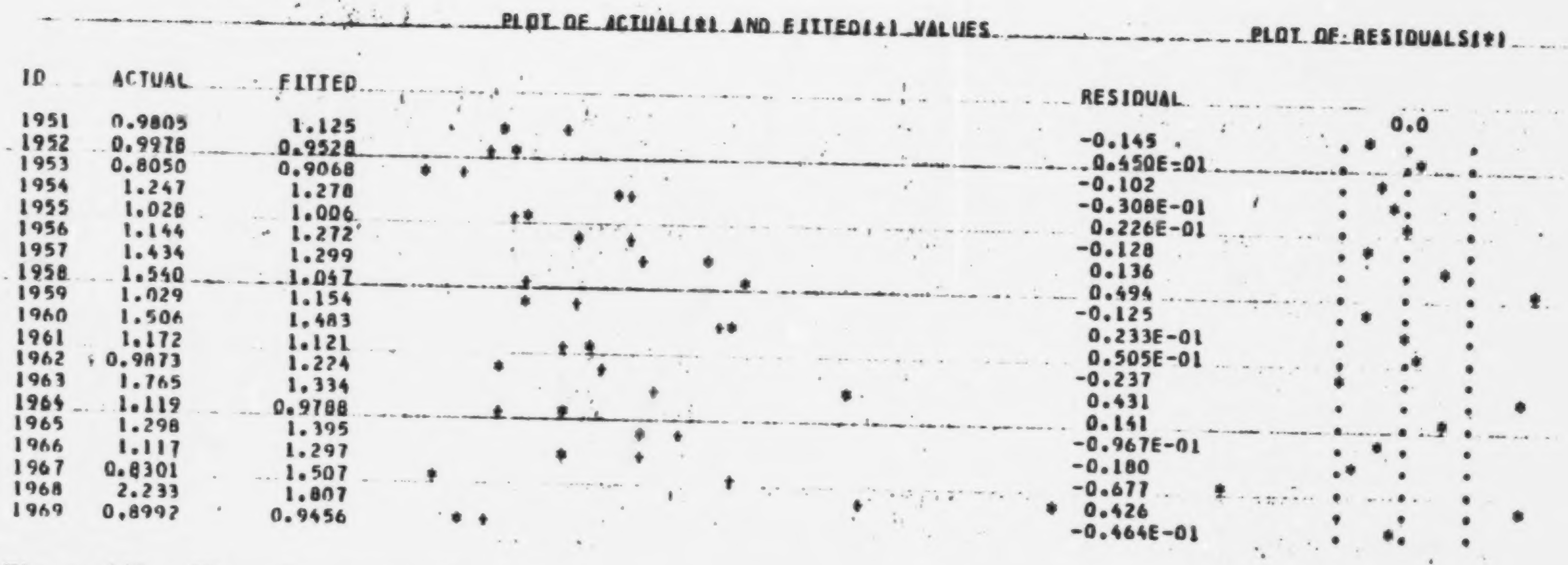
```
                                 PLOT OF ACTUAL(*) AND FITTED(+) VALUES                  PLOT OF RESIDUALS(*)
ID      ACTUAL       FITTED                                       RESIDUAL
                                                                                     0.0
1950     57.42        56.63                                        0.792
1951     56.66        56.40                                        0.264
1952     60.28        61.15                                       -0.875
1953     56.46        59.57                                       -3.11
1954     59.52        57.98                                        1.54
1955     61.33        59.11                                        2.22
1956     46.06        52.04                                       -5.98
1957     58.82        57.06                                        1.76
1958     71.50        61.20                                        10.3
1959     58.56        58.23                                        0.325
1960     62.60        64.50                                       -1.90
1961     66.86        63.83                                        3.04
1962     68.09        68.33                                       -0.246
1963     62.66        66.48                                       -3.82
1964     62.18        63.01                                       -0.833
1965     62.78        64.95                                       -2.17
1966     61.73        63.33                                       -1.60
1967     60.01        60.85                                       -0.845
1968     57.44        57.54                                       -0.960E-01
1969     58.81        57.57                                        1.23
```

Figure 133. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1950 Through 1969: West Virginia (OLS)



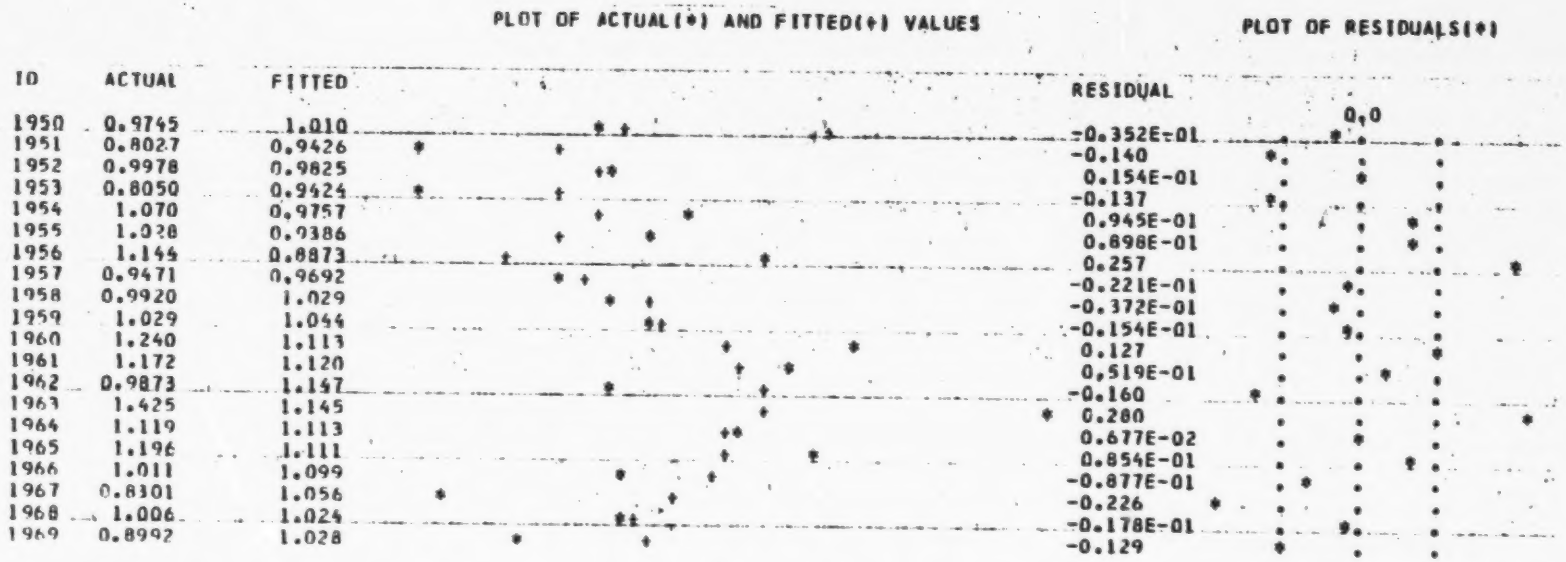
```
ID      ACTUAL      FITTED      RESIDUAL
1950    73.97       71.17        2.80
1951    70.03       71.96       -1.93
1952    71.21       67.55        3.66
1953    57.51       61.98       -4.47
1954    53.11       49.37        3.74
1955    53.76       50.75        3.01
1956    38.77       48.74       -9.97
1957    46.34       46.10        0.240
1958    51.17       43.41        7.76
1959    38.02       37.25        0.772
1960    38.27       39.07       -0.795
1961    39.64       38.14        1.50
1962    38.07       39.89       -1.81
1963    34.41       38.27       -3.87
1964    32.36       35.48       -3.11
1965    32.15       34.91       -2.76
1966    30.88       31.31       -0.428
1967    29.67       28.69        0.981
1968    28.60       27.74        0.860
1969    30.93       27.11        3.82
```

Figure 134. Plots for Nonfatal Injury Rate Per Million Tons, 1950 Through 1969: West Virginia (OLS)



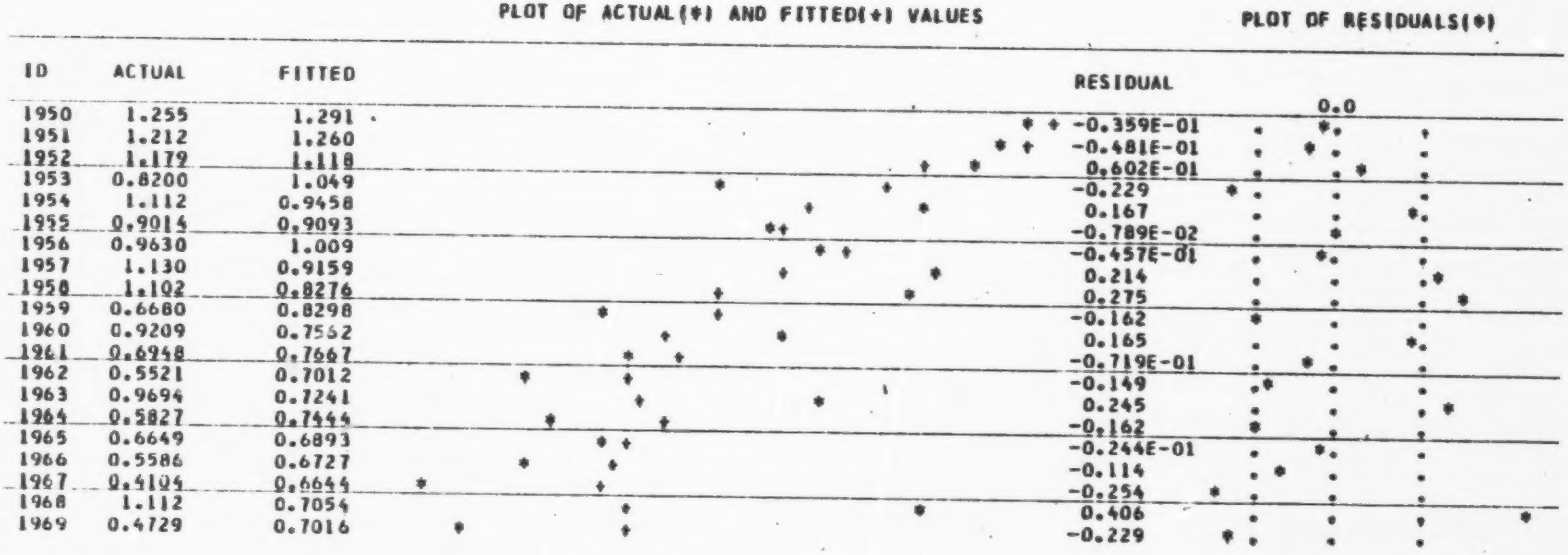
```
---------------PLOT OF ACTUAL(*) AND FITTED(+) VALUES-------------------PLOT OF RESIDUALS(*)---
ID     ACTUAL       FITTED                                        RESIDUAL                 0.0
1951   0.9805        1.125                                        -0.145
1952   0.9978       0.9528                                         0.450E-01
1953   0.8050       0.9068                                        -0.102
1954    1.247        1.278                                        -0.308E-01
1955    1.028        1.006                                         0.226E-01
1956    1.144        1.272                                        -0.128
1957    1.434        1.299                                         0.136
1958    1.540        1.047                                         0.494
1959    1.029        1.154                                        -0.125
1960    1.506        1.483                                         0.233E-01
1961    1.172        1.121                                         0.505E-01
1962   0.9873        1.224                                        -0.237
1963    1.765        1.334                                         0.431
1964    1.119       0.9788                                         0.141
1965    1.298        1.395                                        -0.967E-01
1966    1.117        1.297                                        -0.180
1967   0.8301        1.507                                        -0.677
1968    2.233        1.807                                         0.426
1969   0.8992       0.9456                                        -0.464E-01
```

Figure 135. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1969: West Virginia (CORC)



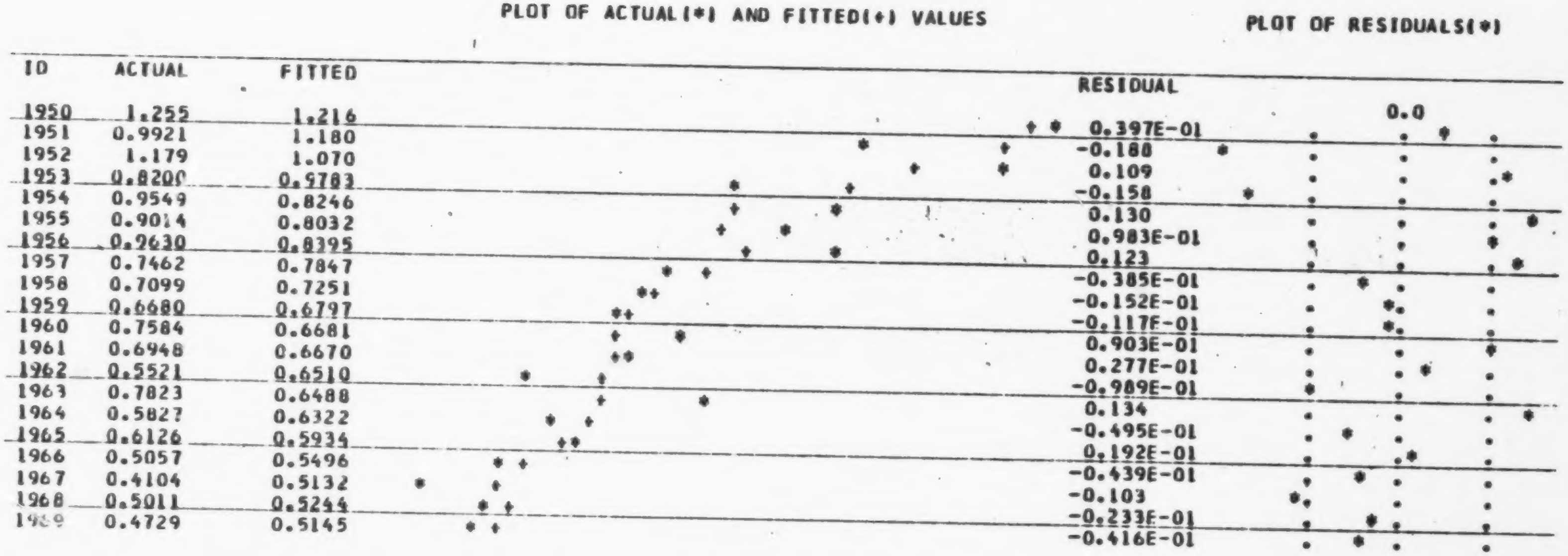
```
                                   PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID      ACTUAL        FITTED                                              RESIDUAL
                                                                                          0,0
1950    0.9745        1.010                                              -0.352E-01
1951    0.8027        0.9426                                             -0.140
1952    0.9978        0.9825                                              0.154E-01
1953    0.8050        0.9424                                             -0.137
1954     1.070        0.9757                                              0.945E-01
1955     1.028        0.9386                                              0.898E-01
1956     1.144        0.8873                                              0.257
1957    0.9471        0.9692                                             -0.221E-01
1958    0.9920         1.029                                             -0.372E-01
1959     1.029         1.044                                             -0.154E-01
1960     1.240         1.113                                              0.127
1961     1.172         1.120                                              0,519E-01
1962    0.9873         1.147                                             -0.160
1963     1.425         1.145                                              0.280
1964     1.119         1.113                                              0.677E-02
1965     1.196         1.111                                              0.854E-01
1966     1.011         1.099                                             -0.877E-01
1967    0.8301         1.056                                             -0.226
1968     1.006         1.024                                             -0.178E-01
1969    0.8992         1.028                                             -0.129
```

Figure 136. Plots for Fatal Injury Rate Excluding Disasters Per Million Man-Hours, 1950 Through 1969: West Virginia (OLS)



```
                                   PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(*)

ID      ACTUAL        FITTED                                                   RESIDUAL
                                                                                            0.0
1950    1.255         1.291
1951    1.212         1.260                                                 -0.359E-01
1952    1.179         1.118                                                 -0.481E-01
1953    0.8200        1.049                                                  0.602E-01
1954    1.112         0.9458                                                -0.229
1955    0.9014        0.9093                                                 0.167
1956    0.9630        1.009                                                 -0.789E-02
1957    1.130         0.9159                                                -0.457E-01
1958    1.102         0.8276                                                 0.214
1959    0.6680        0.8298                                                 0.275
1960    0.9209        0.7562                                                -0.162
1961    0.6948        0.7667                                                 0.165
1962    0.5521        0.7012                                                -0.719E-01
1963    0.9694        0.7241                                                -0.149
1964    0.5827        0.7444                                                 0.245
1965    0.6649        0.6893                                                -0.162
1966    0.5586        0.6727                                                -0.244E-01
1967    0.4104        0.6644                                                -0.114
1968    1.112         0.7054                                                -0.254
1969    0.4729        0.7016                                                 0.406
                                                                            -0.229
```

Figure 137. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1969: West Virginia (OLS)



```
ID      ACTUAL     FITTED     RESIDUAL

1950    1.255      1.216       0.397E-01
1951    0.9921     1.180      -0.180
1952    1.179      1.070       0.109
1953    0.8200     0.9783     -0.158
1954    0.9549     0.8246      0.130
1955    0.9014     0.8032      0.983E-01
1956    0.9630     0.8395      0.123
1957    0.7462     0.7847     -0.385E-01
1958    0.7099     0.7251     -0.152E-01
1959    0.6680     0.6797     -0.117E-01
1960    0.7584     0.6681      0.903E-01
1961    0.6948     0.6670      0.277E-01
1962    0.5521     0.6510     -0.989E-01
1963    0.7823     0.6488      0.134
1964    0.5827     0.6322     -0.495E-01
1965    0.6126     0.5934      0.192E-01
1966    0.5057     0.5496     -0.439E-01
1967    0.4104     0.5132     -0.103
1968    0.5011     0.5244     -0.233E-01
1969    0.4729     0.5145     -0.416E-01
```

Figure 138. Plots for Fatal Injury Rate Excluding Disasters Per Million Tons, 1950 Through 1969: West Virginia (OLS)

Table 75

Comparison of Predicted Levels of Injury Rates Based on Multiple Regressions With Actual Injury Rates: West Virginia[‡]

Injury Rate		Year					
		1970	1971	1972	1973	1974	1975
NFRMH (OLS)	Predicted	53.34 (±9.09)	52.69 (±9.60)	53.50 (±8.99)	55.25 (±8.85)	57.57 (±8.45)	58.92 (±8.37)
	Actual	64.09	63.65	65.81	61.08	60.11	57.12
NFRPR (OLS)	Predicted	26.97 (±10.88)	26.92 (±11.72)	29.72 (±11.23)	30.79 (±11.22)	27.33 (±10.71)	27.74 (±10.83)
	Actual	37.98	47.44	47.72	45.65	47.16	53.24
FRMH (CORC)	Predicted	1.56 (±0.81)	1.63 (±0.86)	1.47 (±0.79)	2.18 (±0.78)	1.49 (±0.73)	1.50 (±0.72)
	Actual	0.88	0.50	0.62	0.53	0.47	0.38
FRMHND(OLS)	Predicted	0.98 (±0.37)	1.00 (±0.39)	0.94 (±0.36)	0.95 (±0.36)	1.03 (±0.34)	1.06 (±0.34)
	Actual	0.88	0.50	0.43	0.53	0.47	0.38
FRPR (OLS)	Predicted	0.76 (±0.53)	0.80 (±0.57)	0.78 (±0.55)	0.75 (±0.55)	0.72 (±0.52)	0.72 (±0.53)
	Actual	0.52	0.37	0.45	0.40	0.37	0.35
FRPRND(OLS)	Predicted	0.54 (±0.27)	0.55 (±0.29)	0.55 (±0.28)	0.54 (±0.28)	0.51 (±0.26)	0.51 (±0.27)
	Actual	0.52	0.37	0.31	0.40	0.37	0.35

[‡] Prediction intervals for a 95.0 percent confidence level are given in parentheses.

FRMHND may not be very reliable since the R-squared value for the prediction equation is 26 percent. Actual fatal injury rates per million tons are lower than predicted values; however, none of these differences are statistically significant at the 95.0 percent confidence level.

The results of the models using data through 1975 were used to make predictions of injury rates without the Mine Act. These predictions are presented in Tables 76 and 77. For NFRMH, the predicted rates without MACT are lower than actual values in 1970 through 1972. In 1973 through 1975, actual rates fall within the 95.0 percent confidence interval of the predicted rates. For NFRPR, the coefficient of MACT is positive and significant; therefore, predicted injury rates are less than actual rates for all years. Fatal injury rates per million man hours (FRMH and FRMHND) have predicted injury rates that are greater than actual values in all years except for FRMHND in 1970. The predicted values for FRPR are significantly greater than actual values in 1970, 1971, 1974, and 1975. The predicted values for FRPRND are significantly greater than actual values in 1970 through 1972. Tables 76 and 77 also show the percentage decreases in injury rates due to MACT. For example, in 1975, actual NFRMH is up as compared to the predicted rate without MACT by 0.8 percent, and NFRPR is up by 42.4 percent. This is not the expected effect of MACT, since actual rates should be less than predicted without MACT. The corresponding comparisons for fatal injury rates, showing that MACT has the expected effects, are: actual FRMH is reduced by 54.5 percent, actual FRMHND is reduced by 47.0 percent, actual FRPR is reduced by 37.7 percent, and actual FRPRND is reduced by 25.5 percent.

Table 76

Effect of MACT on Nonfatal Injury Rates: West Virginia

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Nonfatal Injuries Per Million Man-Hours								
NFRMH	1969	-0.134	0.012	0.158	0				61.10				58.81	
	1970				5.15924	-0.82	-0.06	0.69	59.01	58.19	58.95	59.70	64.09	-0.1
	1971				10.4678	-1.65	-0.13	1.40	59.04	57.39	58.91	60.44	63.65	-0.2
	1972				29.2330	-4.62	-0.35	3.92	59.12	54.50	58.77	63.04	65.81	-0.6
	1973				42.6833	-6.74	-0.51	5.72	60.03	53.29	59.52	65.75	61.08	-0.9
	1974				52.0947	-8.23	-0.63	6.98	61.98	53.75	61.35	68.96	60.11	-1.0
	1975				39.1479	-6.19	-0.47	5.25	62.67	56.48	62.20	67.92	57.12	-0.8
						Nonfatal Injuries Per Million Tons								
NFRPR	1969	0.157	0.355	0.553	0				31.25				30.93	
	1970				5.15924	-2.85	-1.83	-0.81	35.29	32.44	33.46	34.48	37.98	-5.5
	1971				10.4678	-5.79	-3.72	-1.64	38.59	32.80	34.87	36.95	47.44	-10.8
	1972				29.2330	-16.17	-10.38	-4.59	46.12	29.95	35.74	41.53	47.72	-29.0
	1973				42.6833	-23.60	-15.15	-6.70	50.68	27.08	35.53	43.98	45.65	-42.6
	1974				52.0947	-28.81	-18.49	-8.18	50.90	22.09	32.41	42.72	47.16	-57.1
	1975				39.1479	-21.65	-13.90	-6.15	46.70	25.05	32.80	40.55	53.24	-42.4

Table 77

Effect of MACT on Fatal Injury Rates: West Virginia

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Fatal Injuries Per Million Man-Hours								
FRMH	1969	-0.029	-0.017	-0.005	0				1.20				0.90	
	1970				5.15924	0.03	0.09	0.15	1.03	1.06	1.12	1.18	0.88	8.0
	1971				10.4678	0.05	0.18	0.30	0.92	0.97	1.10	1.22	0.50	16.4
	1972				29.2330	0.15	0.50	0.85	0.63	0.78	1.13	1.48	0.62	44.2
	1973				42.6833	0.21	0.73	1.24	0.43	0.64	1.16	1.67	0.53	62.9
	1974				52.0947	0.26	0.87	1.51	0.31	0.57	1.20	1.82	0.47	74.2
	1975				39.1479	0.20	0.67	1.14	0.56	0.76	1.23	1.70	0.38	54.5
						Fatal Injuries Excluding Disasters Per Million Man-Hours								
FRMHND	1969	-0.016	-0.012	-0.008	0				0.96				0.90	
	1970				5.15924	0.04	0.06	0.08	0.81	0.85	0.87	0.89	0.88	6.9
	1971				10.4678	0.08	0.13	0.17	0.74	0.82	0.87	0.91	0.50	14.9
	1972				29.2330	0.23	0.35	0.47	0.53	0.76	0.88	1.00	0.43	39.8
	1973				42.6833	0.34	0.51	0.68	0.40	0.74	0.91	1.08	0.53	56.0
	1974				52.0947	0.42	0.63	0.83	0.35	0.77	0.98	1.18	0.47	64.3
	1975				39.1479	0.31	0.47	0.63	0.53	0.84	1.00	1.16	0.38	47.0
						Fatal Injuries Per Million Tons								
FRPR	1969	-0.014	-0.006	0.002	0				0.61				0.47	
	1970				5.15924	-0.04	0.03	0.07	0.59	0.58	0.62	0.66	0.52	4.8
	1971				10.4678	-0.02	0.06	0.15	0.57	0.55	0.63	0.72	0.37	9.5
	1972				29.2330	-0.06	0.18	0.41	0.47	0.41	0.65	0.88	0.45	27.7
	1973				42.6833	-0.09	0.26	0.60	0.39	0.30	0.65	0.99	0.40	40.0
	1974				52.0947	-0.10	0.31	0.73	0.30	0.20	0.61	1.03	0.37	50.8
	1975				39.1479	-0.08	0.23	0.55	0.38	0.30	0.61	0.93	0.35	37.7

Table 77 (Continued)

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT Mean			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
						Low	Mean	High		Low	Mean	High		
						Fatal Injuries Excluding Disasters Per Million Tons								
FRPRND	1969	-0.007	-0.003	0.001	0				0.50				0.47	
	1970				5.15924	-0.01	0.02	0.04	0.47	0.46	0.49	0.51	0.52	4.1
	1971				10.4678	-0.01	0.03	0.07	0.46	0.45	0.49	0.53	0.37	6.1
	1972				29.2330	-0.03	0.09	0.20	0.41	0.38	0.50	0.61	0.31	18.0
	1973				42.6833	-0.04	0.13	0.30	0.37	0.33	0.50	0.67	0.40	26.0
	1974				52.0947	-0.05	0.16	0.36	0.31	0.26	0.47	0.67	0.37	34.0
	1975				39.1479	-0.04	0.12	0.27	0.35	0.31	0.47	0.62	0.35	25.5

Summary

The relationships of the independent variables to the injury rates may be summarized as follows. For nonfatal injury rates per million man-hours: (1) weighted-average seam thickness is negatively related but not significant; (2) percent mechanically loaded is positively related and not significant; (3) average production is negatively related and significant; and (4) the Mine-Act variable is positively related and not significant. For nonfatal injury rates per million tons: (1) weighted-average seam thickness is positively related and not significant; (2) percent mechanically loaded is negatively realted and significant; (3) weighted-average employment is positively related and significant; and (4) the Mine-Act variable is positively related and significant. For fatal injury rate per million man-hours (FRMH): (1) weighted-average seam thickness is negatively related but not significant; (2) percent mechanically loaded is positively related but not significant; (3) average production is negatively related and not significant; and (4) the Mine-Act variable is negatively related and significant. Excluding disasters (FRMHND): (1) weighted-average seam thickness is positively related and significant; (2) percent mechanically loaded is negatively related but not significant; (3) average production is positively related and significant; and (4) the Mine-Act variable is negatively related and significant. For fatal injury rates per million tons (FRPR and FRPRND): (1) weighted-average seam thickness is negatively related but not significant; (2) percent mechanically loaded is negatively related and significant; (3) weighted-average employment is positively related and not significant; and (4) the Mine-Act variable is negatively related and significant.

The effects of each independent variable on the injury rates may be summarized as follows: (1) an increase in ST of one inch decreases NFRMH by 1.75, increases NFRPR by 0.48, decreases FRMH by 0.08, increases FRMHND by 0.08, decreases FRPR by 0.012, and decreases FRPRND by 0.02; (2) an increase in PMECH of one percent increases NFRMH by 0.34, decreases NFRPR by 1.35, increases FRMH by 0.02, decreases FRMHND by 0.007, decreases FRPR by 0.02, and decreases FRPRND by 0.03; (3) an increase in AP of one million tons decreases NFRMH by 49.0, decreases FRMH by 1.2, and decreases FRMHND by 1.7; (4) an increase in AEMPL of 10 increases NFRPR by 2.7, increases FRPR by 0.03, and increases FRPRND by 0.02; (5) an increase in the value of the Mine-Act variable of one increases NFRMH by 0.01, increases NFRPR by 0.36, decreases FRMH by 0.02, decreases FRMHND by 0.01, decreases FRPR by 0.01, and decreases FRPRND by 0.003.

The results suggest that the Mine Act may have reduced fatal injury rates but not nonfatal injury rates.

Pennsylvania

Data and Trends of Variables

The data used for Pennsylvania are presented in Table 78. The state data on injuries, total production and average production, man-days worked, weighted-average seam thickness, and weighted-average employment were obtained from the Pennsylvania Annual Report on Mining, Oil and Gas, and Land Reclamation and Conservation Activities for 1950 through 1975. The nonfatal injuries reported in 1950 and 1951--798 and 818--are totally out of line compared with the numbers for succeeding years (Table 78). For 1952, the number of nonfatal injuries reported is 3,256. This increase of almost 400 percent leads me to believe that a change was made in the criteria used to define a nonfatal injury. Therefore, regressions were made on data from 1952 through 1975 for which a consistent definition of an injury was used. Other data sources are as given in the section on methods of investigation.

The trends over time of the accident rates studied are shown in Figures 139 through 144. Nonfatal injury rates per million man-hours (NFRMH) show an overall decreasing trend from 1952 through 1968, an increasing trend through 1972, then decreasing values in 1973 and 1974, with an increase in 1975 (Figure 139). Piecewise regression results (Table 79) show that a break in trend in 1969 from decreasing to increasing values is significant at a 99.0 percent confidence level. Furthermore, better results are obtained by regressing with a join point in 1968. Nonfatal injury rates per million tons (NFRPR) also follow a downward trend through 1968, with an increasing trend thereafter (Figure 140). As with NFRMH, a break in trend in 1969 (and 1968) from

Table 78

Data for Pennsylvania Injury Model

Year	Number of Nonfatal Injuries NFTL	Nonfatal Injury Rate Per Million Man-Hours NFRMH	Nonfatal Injury Rate Per Million Tons NFRPR	Total Number of Fatal Injuries FTL	Number of Disaster Fatalities DFTL	Fatal Injury Rate Per Million Man-Hours FRMH	Fatal Injury Rate Excluding Disaster Fatalities Per Million Man-Hours FRMHND
1950	798	---	---	76	0	0.600902	0.600902
1951	818	---	---	62	0	0.476027	0.476027
1952	3256	32.7152	48.2542	58	6	0.582766	0.522479
1953	2872	29.5092	40.0535	63	0	0.647312	0.647312
1954	1635	25.6465	30.3804	41	0	0.643122	0.643122
1955	1846	25.3278	28.8438	37	0	0.507653	0.507653
1956	1949	27.0855	29.3300	47	0	0.653166	0.653166
1957	1742	27.4847	27.5835	48	6	0.757329	0.662663
1958	1145	26.5460	24.0798	24	0	0.556423	0.556423
1959	957	26.1426	21.5058	29	0	0.792201	0.792201
1960	925	27.0515	20.9852	22	0	0.643387	0.643387
1961	861	28.0252	20.6247	20	0	0.650992	0.650992
1962	679	24.4309	15.8560	54	37	1.94296	0.611672
1963	698	24.4010	15.1171	16	0	0.559336	0.559336
1964	711	23.1705	13.6101	16	0	0.521417	0.521417
1965	682	22.0172	12.2593	[illegible]	0	0.871649	0.871649
1966	696	22.8112	12.4445	24	5	0.786593	0.622720
1967	646	22.0123	11.4170	23	0	0.783719	0.783719
1968	619	22.1648	11.3745	28	0	1.00261	1.00261
1969	845	27.3555	15.0839	19	0	0.615095	0.615095
1970	881	26.6996	15.9750	25	0	0.757652	0.757652
1971	801	26.6042	18.1111	27	0	0.896771	0.896771
1972	1263	35.3430	25.7378	17	0	0.475718	0.475718
1973	1183	33.0273	25.5393	12	0	0.335019	0.335019
1974	923	26.3194	21.8505	15	0	0.427727	0.427727
1975	1288	29.8332	28.5545	11	0	0.254786	0.254786

Table 78 (Continued)

Year	Fatal Injury Rate Per Million Tons FRPR	Fatal Injury Rate Excluding Disaster Fatalities Per Million Tons FRPRND	Total Production TPROD X 10^{-6} (millions of short tons)	Number of Man-Days Worked MNDY X 10^{-6} (millions of man-days)	Weighted-Average Seam Thickness ST (inches)	Percent of Coal Loaded Mechanically PMECH	Weighted-Average Employment AEMPL	Average Production AP X 10^{6} (short tons)	Number of Inspections Per Mine Under CMHSA MACT
1950	0.974630	0.974630	77.9783	15.8096	64.72	64.11	46	82429.4	0.0
1951	0.738223	0.738223	83.9855	16.2806	64.84	68.70	53	100102	0.0
1952	0.859565	0.770644	67.4760	12.4407	64.50	72.19	47	97457.1	0.0
1953	0.878610	0.878610	71.7042	12.1657	66.90	78.80	51	110314	0.0
1954	0.761834	0.761834	53.8175	7.96893	67.19	86.20	40	97850	0.0
1955	0.578127	0.578127	63.9998	8.99466	66.53	90.72	26	70767.4	0.0
1956	0.707291	0.707291	66.4507	7.92259	66.24	91.67	25	75010.1	0.0
1957	0.760050	0.665044	63.1537	5.39158	64.13	92.65	18	58343.8	0.0
1958	0.504730	0.504730	47.5502	4.57586	65.95	93.51	16	57866.9	0.0
1959	0.651690	0.651690	44.4997	4.27586	66.30	93.91	17	62170.4	0.0
1960	0.499106	0.499106	44.0788	4.27426	65.37	95.43	16	62965.3	0.0
1961	0.479088	0.479088	41.7460	3.84029	65.65	96.28	16	71971.2	0.0
1962	1.26101	0.396984	42.8229	3.47409	64.49	96.33	16	79198.6	0.0
1963	0.346524	0.346524	46.1728	3.57567	64.81	96.88	17	99316.9	0.0
1964	0.306274	0.306274	52.2407	3.83570	63.69	97.45	20	116872	0.0
1965	0.485340	0.485340	55.6311	3.87197	62.70	98.49	22	138437	0.0
1966	0.429120	0.339720	55.9284	3.81391	62.62	99.17	26	181936	0.0
1967	0.406489	0.406489	56.5820	3.66841	64.73	99.38	32	215099	0.0
1968	0.514517	0.514517	54.4200	3.49089	63.19	99.54	38	247877	0.0
1969	0.339164	0.339164	56.0201	3.86120	63.22	99.73	47	278528	0.0
1970	0.453320	0.453320	55.1486	4.12458	62.48	99.62	57	255648	5.15924
1971	0.610486	0.610486	44.2270	3.76350	63.85	99.73	60	324979	10.4678
1972	0.346431	0.346431	49.0718	4.46694	63.14	99.77	81	356319	29.2330
1973	0.259063	0.259063	46.3208	4.47736	63.65	99.87	94	356314	42.6833
1974	0.355101	0.355101	42.2415	4.38364	62.66	99.83	97	340657	52.0947
1975	0.243866	0.243866	45.1067	5.39668	61.34	99.79	112	341717	39.1479

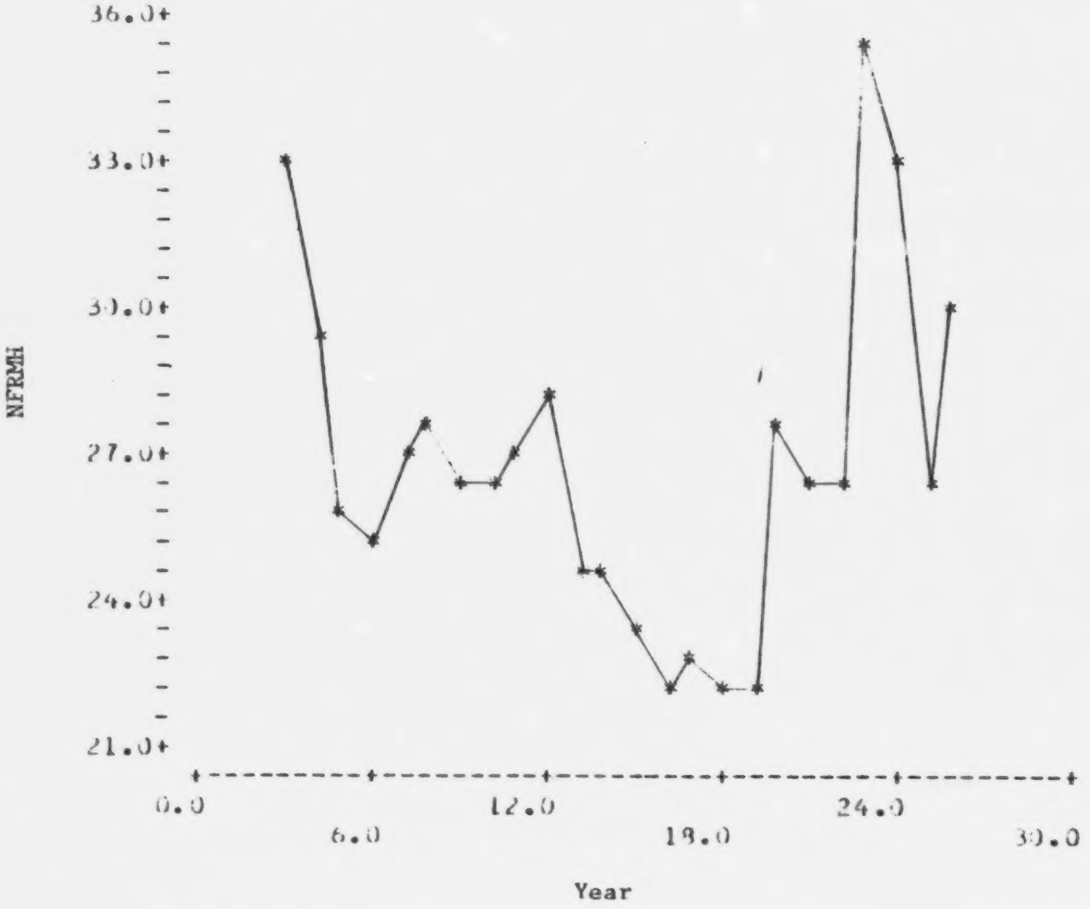


Figure 139. Trend of Nonfatal Injury Rate Per Million Man-Hours: Pennsylvania (1952 Through 1975)

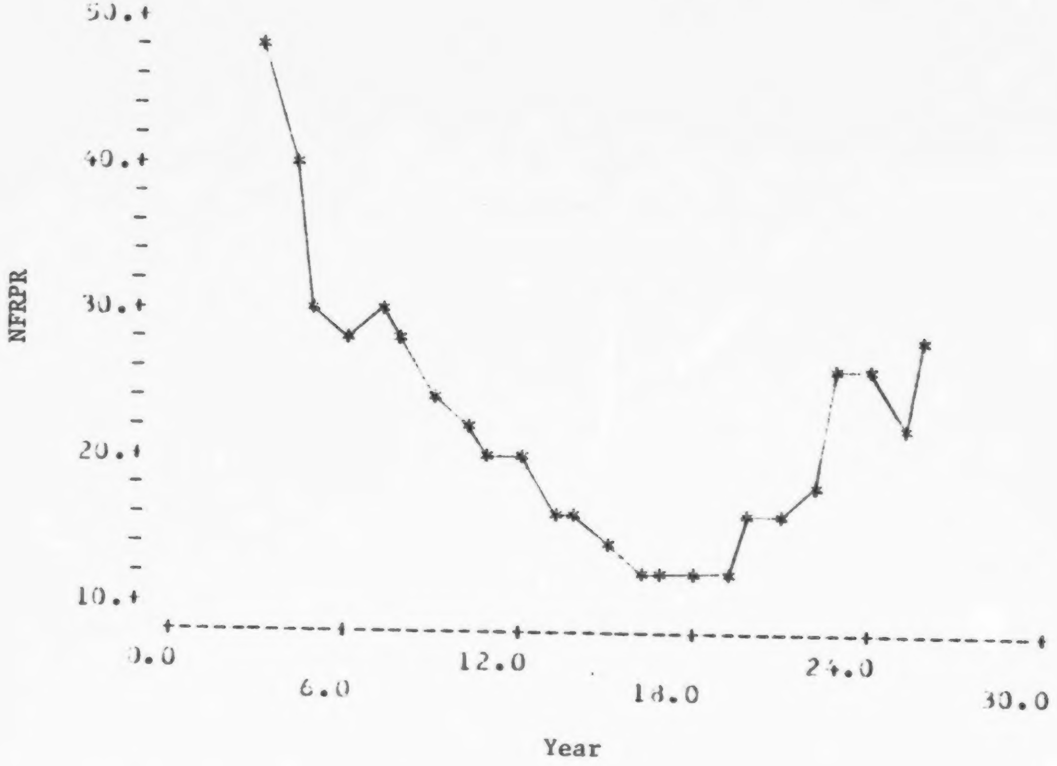


Figure 140. Trend of Nonfatal Injury Rate Per Million Tons: Pennsylvania (1952 Through 1975)

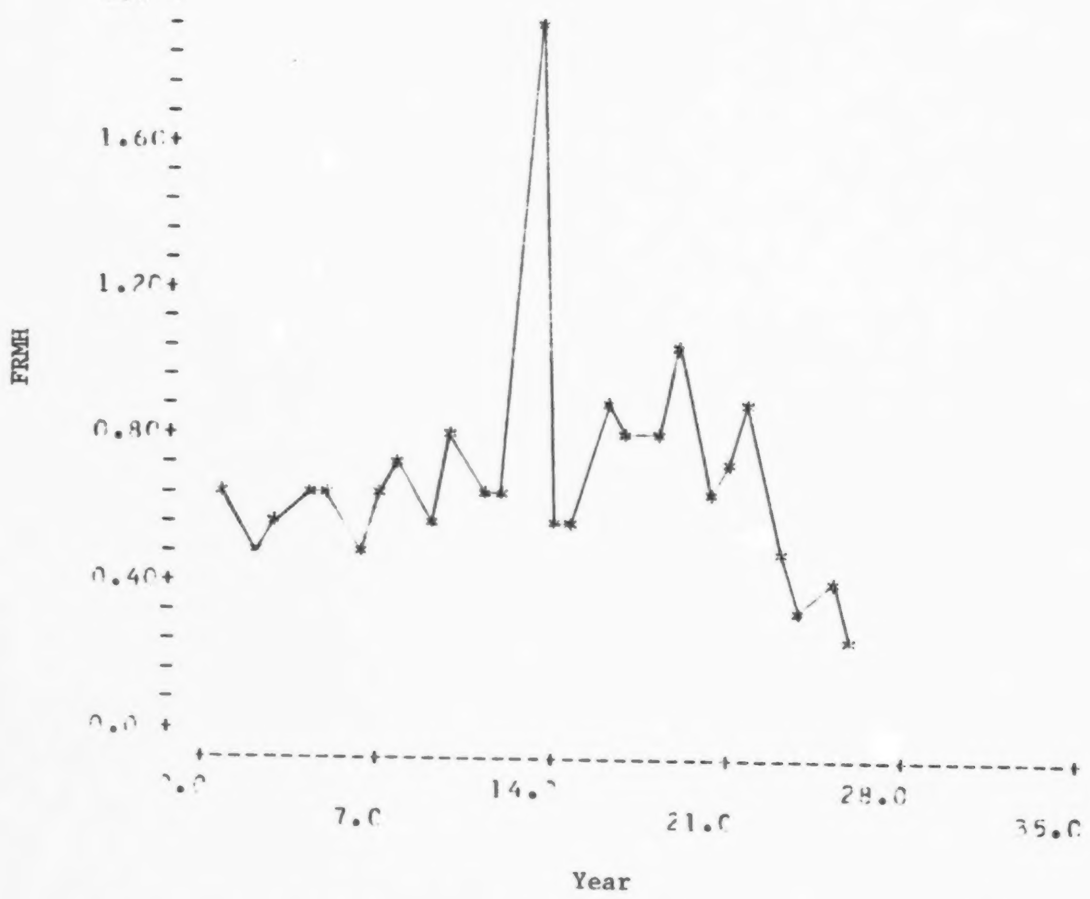


Figure 141. Trend of Fatal Injury Rate Per Million Man-Hours: Pennsylvania (1950 Through 1975)

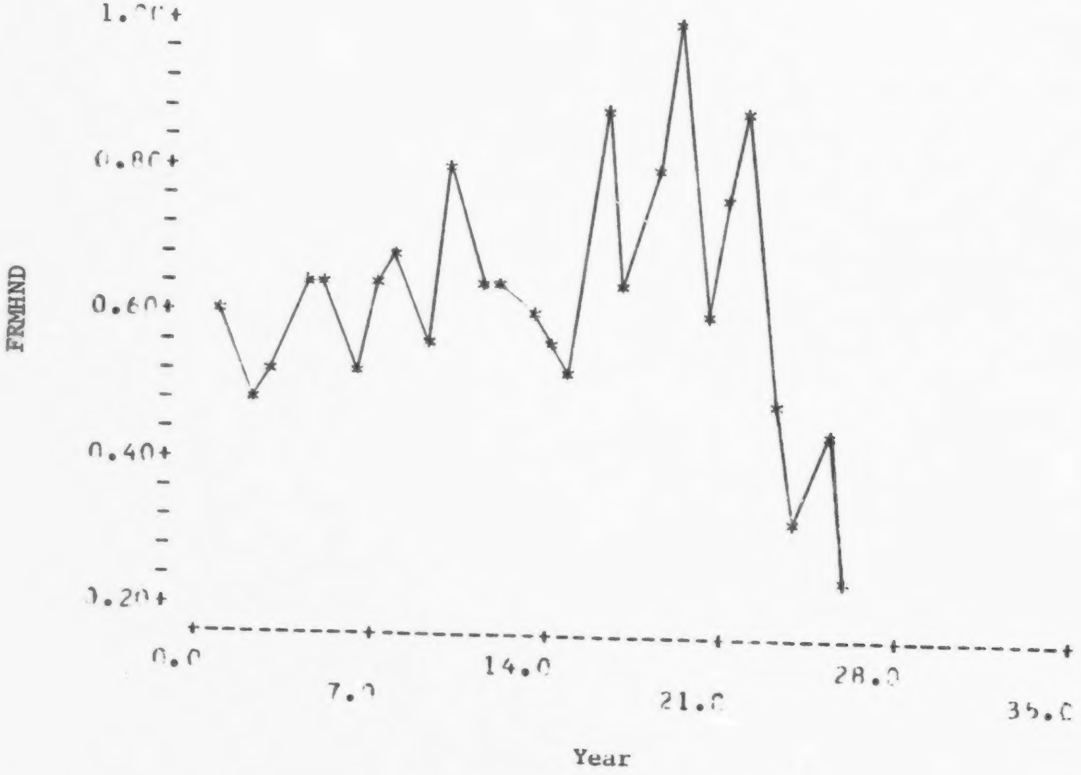


Figure 142. Trend of Fatal Injury Rate Excluding Disasters Per Million Man-Hours: Pennsylvania (1950 Through 1975)

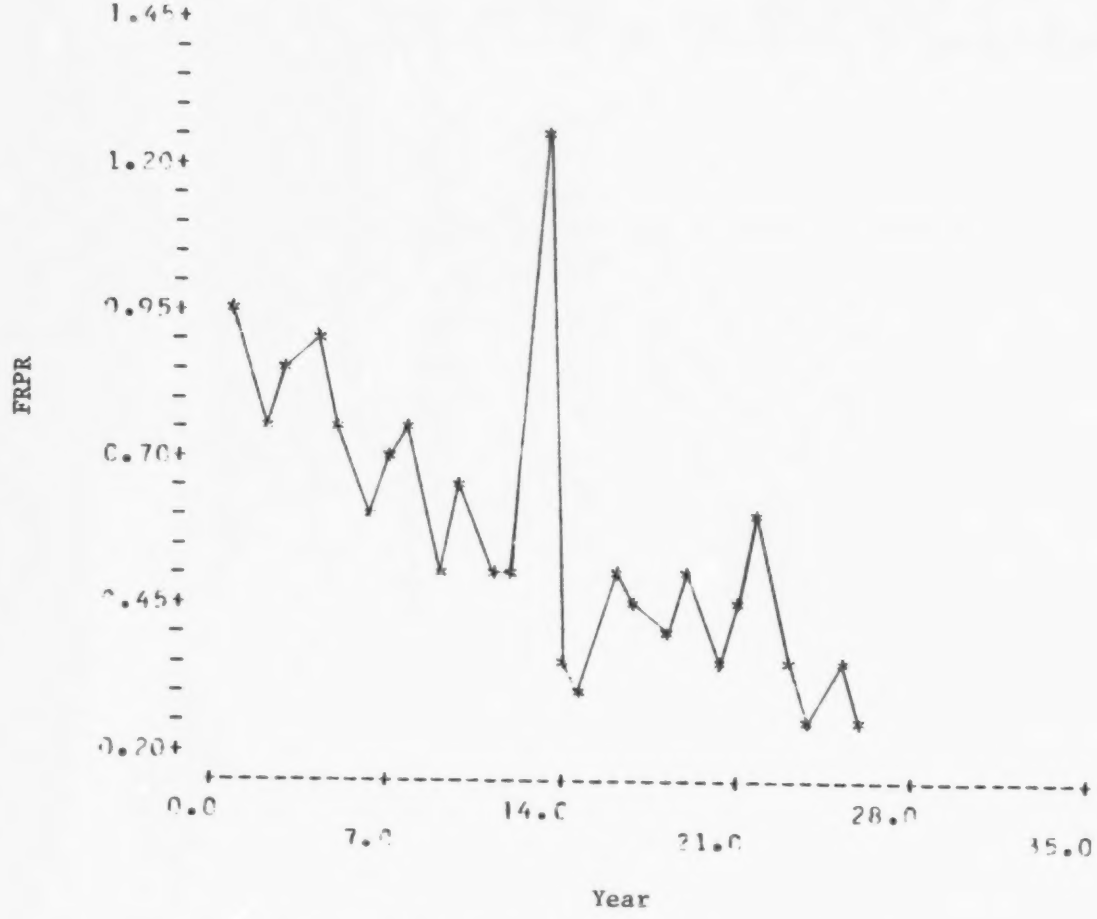


Figure 143. Trend of Fatal Injury Rate Per Million Tons: Pennsylvania (1950 Through 1975)

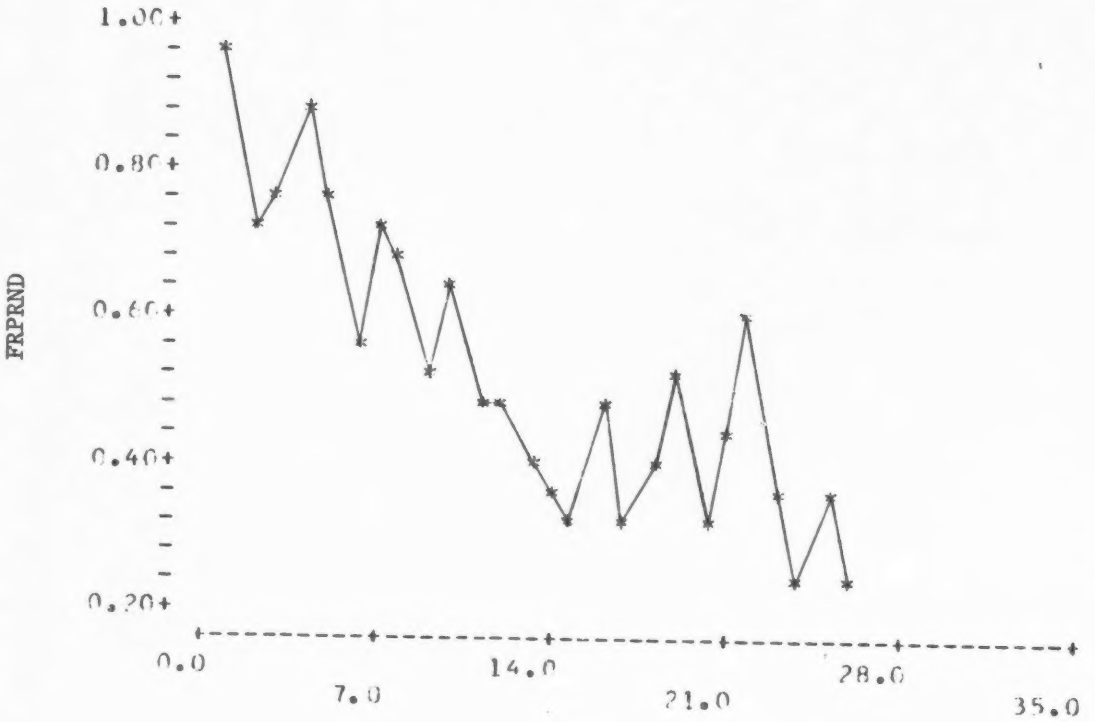


Figure 144. Trend of Fatal Injury Rate Excluding Disasters Per Million Tons: Pennsylvania (1950 Through 1975)

Table 79

Piecewise Regression Results for Injury Rates: Pennsylvania

Equation Dependent Variable	Constant	X_1	$X_2(X_1 - 19)$ joinpoint of 1968	$X_2(X_1 - 20)$ joinpoint of 1969	R^2	S	F-statistic
20 NFRMH	29.33 (1.58)	-0.283 (0.120) **		1.729 (0.478) ****	0.39	2.85	$6.60_{(2,21)}$
21 NFRMH	30.06 (1.50)	-0.366 (0.118) ****	1.700 (0.388) ****		0.48	2.62	$9.68_{(2,21)}$
23 NRFPR	41.61 (2.40)	-1.654 (0.182) ****		5.315 (0.724) ****	0.80	4.31	$42.13_{(2,21)}$
23 NFRPR	43.19 (2.11)	-1.838 (0.166) ****	4.923 (0.544) ****		0.85	3.68	$61.51_{(2,21)}$
24 FRMH	0.551 (0.126)	0.0172 (0.0101)		-0.1250 (0.0447) ***	0.26	0.28	$3.96_{(2,23)}$
25 FRMH	0.529 (0.128)	0.0203 (0.0106)	-0.1123 (0.0386)		0.27	0.28	$4.28_{(2,23)}$

Table 79 (continued)

Equation Dependent Variable	Constant	X_1	$X_2(X_1 - 19)$ joinpoint of 1968	$X_2(X_1 - 20)$ joinpoint of 1969	R^2	S	F-statistic
26 FRMHND	0.5143 (0.0556)	0.01346 (0.00443) ****		-0.0956 (0.0197) ****	0.51	0.12	$11.86_{(2,23)}$
27 FRMHND	0.5033 (0.0577)	0.01512 (0.00478) ****	-0.0822 (0.0174) ****		0.49	0.12	$11.22_{(2,23)}$
28 FRPR	0.8766 (0.0831)	-0.02319 (0.00662) ****		0.0048 (0.0294)	0.49	0.18	$11.02_{(2,23)}$
29 FRPRND	0.8408 (0.0501)	-0.02483 (0.00399) ****		0.0222 (0.0178)	0.71	0.11	$28.17_{(2,23)}$

Significance Levels:

** Significant at the 95.0 percent confidence level (two-tail test)
*** Significant at the 97.5 percent confidence level (two-tail test)
**** Significant at the 99.0 percent confidence level (two-tail test)

decreasing to increasing is significant at the 99.0 percent confidence level (Table 79). Fatal injury rates per million man-hours (FRMH) show an overall increasing trend through the late 1960s to early 1970s, then a decreasing trend through 1975 (Figure 141). The outlier in 1962 is due to the 37 disaster fatalities. Piecewise regression reveals that a break in trend in 1969 from increasing to decreasing rates is significant at the 98.0 percent confidence level. With the join point in 1968, the level of confidence is 99.0 percent (Table 79). The fatal injury rate excluding disaster fatalities per million man-hours (FRMHND) shows a similar trend, but does not have outlying points (Figure 142). The piecewise regression results (Table 79) show that there is a significant change in trend from increasing to decreasing rates for join points of 1968 or 1969 (99.0 percent confidence levels). Fatal injury rates per million tons produced, both including disasters (FRPR) and excluding disasters (FRPRND), show overall declining trends from 1950 through 1975 (Figures 143 and 144). There is no evidence in either case for a break in trend in 1969 (Table 79).

The trends for weighted-average seam thickness and average production (Figures 24 and 26) have been described in the section on Pennsylvania in Chapter III. Percent of coal loaded mechanically (Figure 145) increases from around 64.0 percent in 1950 to over 90.0 percent in 1955, then rises more slowly to over 99.0 percent in 1967; in 1975, the value is almost 100 percent. Weighted-average employment (Figure 146) trends downward through 1959, levels off through 1963, then rises through 1975.

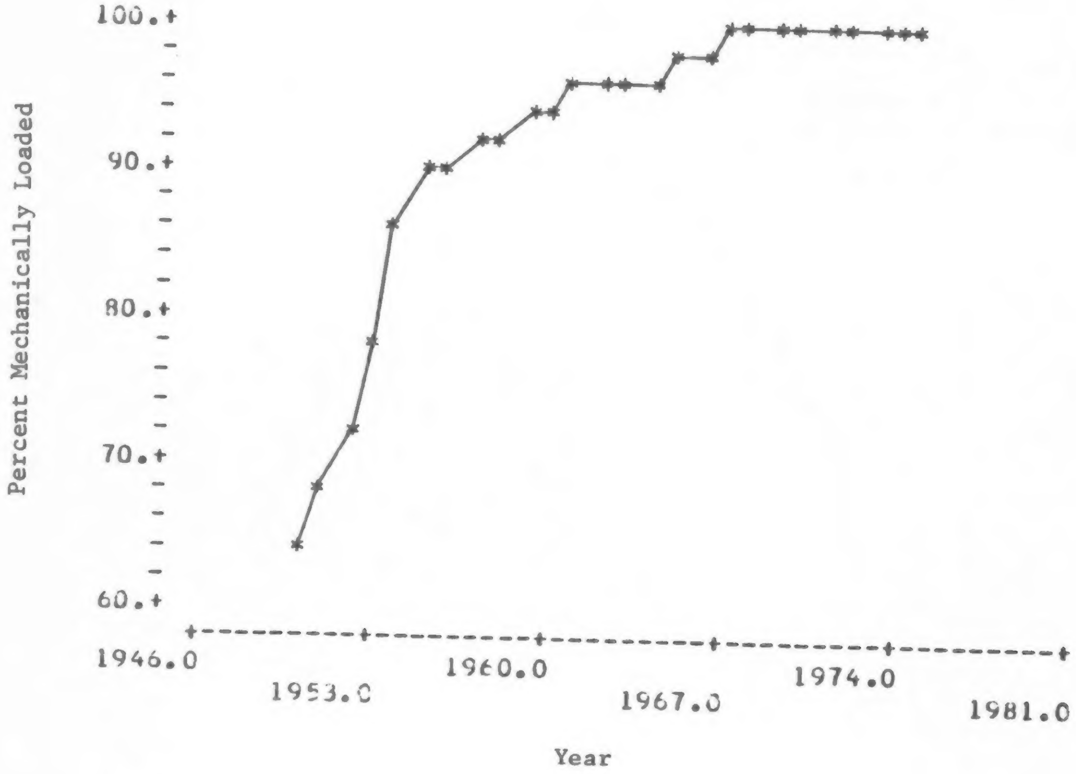


Figure 145. Trend of Percent Mechanically Loaded: Pennsylvania (1950 Through 1975)

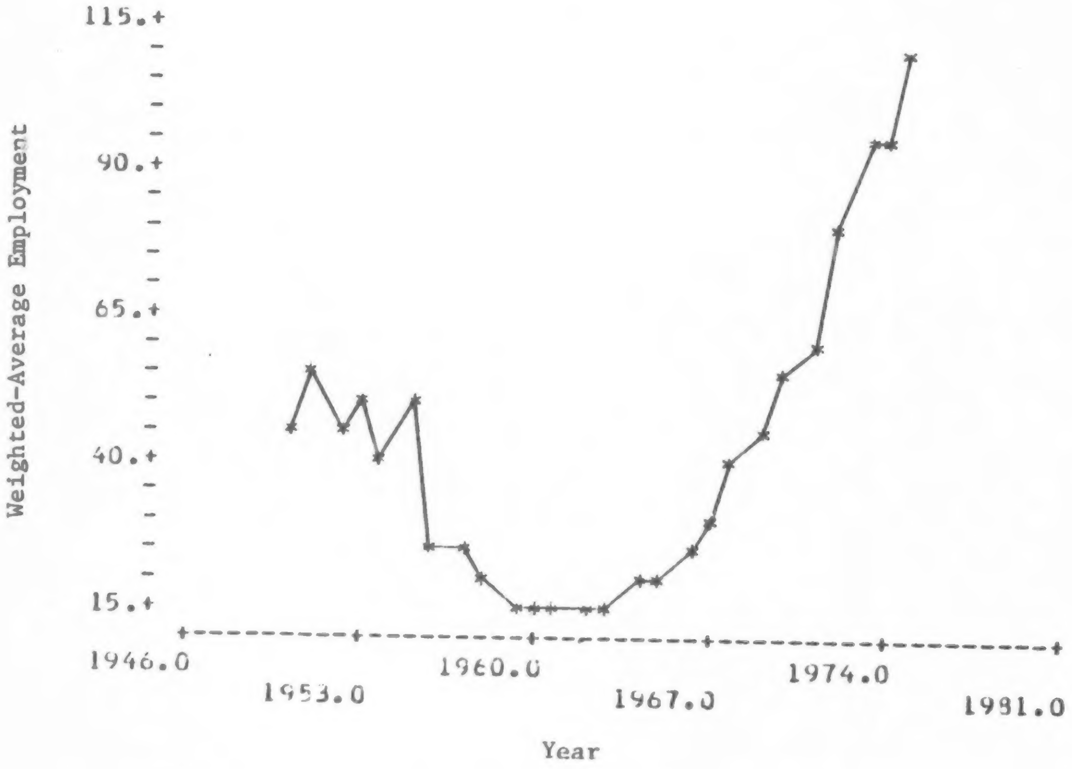


Figure 146. Trend of Weighted-Average Employment: Pennsylvania (1950 Through 1975)

Results of Regressions for 1950 Through 1975

Results for appropriate regressions for the six injury rates are shown in Tables 80 and 81. The correlation matrices for the independent variables are shown in Tables 82, 83, 84, and 85. The greatest pairwise correlations are between MACT and the mine size variables AP (0.82) and AEMPL (0.87). The correlation between AP and ST is around 0.72. Otherwise, pairwise correlations are less than 0.61. Only the OLS regression for NFRPR (Equation 31) has the problem of autocorrelation; this was remedied, however, with the Cochrane-Orcutt technique (Equation 32). Appropriate plots are presented in Figures 147 through 152. There is no evidence of heteroskedasticity in any of the residuals plots.

The regression of NFRMH (Equation 30) results in the coefficient of PMECH being the only significant one at the 90.0 percent confidence level or greater, and the only one having the expected sign. Approximately 53.0 percent of the variance is explained. The regression of NFRPR (Equation 32) results in 93.0 percent of the variance being explained and two significant variables (PMECH and AEMPL). The coefficient of MACT has the expected negative sign, but it is not significant. The regression of FRMH (Equation 33) produces the least satisfactory results, since the equation is not significant at the 95.0 percent confidence level or greater, and the percent of variance explained is only 26.0. However, excluding disasters, the regression of FRMHND (Equation 34) results in 52.0 percent of the variance being explained and the coefficient of MACT being negative, as expected, and significant at the 99.5 percent confidence level. The regression for FRPR (Equation 35) results in 52.0 percent of the variance being

Table 80

Results of Regressions for Injury Model: Pennsylvania (1950 Through 1975)‡

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-correlation (Durbin-Watson statistic)	F-Statistic
30(OLS) NFRMH	30.728 (38.618)	0.313 (0.519)	-0.288 (0.099) #####	14.106 (11.266)		0.097 (0.061)	0.53	2.62	None(1.51)	$5.39_{(4,19)}$
31(OLS) NFRPR	72.547 (39.720)	0.855 (0.496)	-1.177 (0.111) #####		0.111 (0 047) **	0.136 (0.085)	0.93	2.68	+(1.36)	$63.22_{(4,19)}$
32(CORC) NFRPR	277.236 (78.887)	-0.722 (0.549)	-2.261 (0.566) #####		0.203 (0.051) ****	-0.033 (0.085)	0.93	2.16	None(1.75)	$62.94_{(4,18)}$
33(OLS) FRMH	0.642 (3.643)	-0.012 (0.053)	(0.010) (0.007)	-0.515 (1.246)		-0.008 (0.007)	0.26	0.29	None(2.47)	$1.86^{\#}_{(4,21)}$
34(OLS) FRMHND	0.394 (1.598)	-0.004 (0.023)	0.005 (0.003)	0.673 (0.547)		-0.011 (0.003) #####	0.52	0.13	None(2.64)	$5.60_{(4,21)}$

Table 80 (continued)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-correlation (Durbin-Watson statistic)	F-Statistic
35(OLS) FRPR	-0.547 (2.252)	0.036 (0.031)	-0.012 (0.005) ####		-0.001 (0.003)	-0.001 (0.006)	0.52	0.19	None(2.52)	$5.61_{(4,21)}$
36(OLS) FRPRND	-0.530 (1.218)	0.033 (0.017) *	-0.012 (0.003) #####		0.002 (0.002)	-0.004 (0.003) #	0.78	0.10	None(2.12)	$18.53_{(4,21)}$

‡ Except 1952 through 1975 for nonfatal injury rates.

‡‡ The equation is not significant at the 95.0 percent confidence level.

Significance Levels:
* Significant at the 90.0 percent confidence level (two-tail test)
** Significant at the 95.0 percent confidence level (two-tail test)
**** Significant at the 99.0 percent confidence level (two-tail test)
# Significant at the 90.0 percent confidence level (one-tail test)
Significant at the 99.0 percent confidence level (one-tail test)
Significant at the 90.0 percent confidence level (one-tail test)

Table 81

Ninety-Five Percent Confidence Intervals for Coefficients in Pennsylvania Regressions of Injury Model (1950 Through 1975‡)

Equation Dependent Variable	ST		PMECH		AP		AEMPL		MACT	
30(OLS) NFRMH	-0.77	1.40	-0.50	-0.08	-9.47	37.69			-0.03	0.22
31(OLS) NFRPR	-0.18	1.89	-1.41	-0.94			0.01	0.21	-0.04	0.31
32(CORC) NFRPR	-1.88	0.43	-3.45	-1.07			0.10	0.31	-0.21	0.15
33(OLS) FRMH	-0.12	0.10	-0.00	0.02	-3.11	2.08			-0.02	0.01
34(OLS) FRMHND	-0.05	0.04	-0.00	0.01	-0.46	1.81			-0.02	-0.00
35(OLS) FRPR	-0.03	0.10	-0.02	-0.00			-0.01	0.01	-0.01	0.01
36(OLS) FRPRND	-0.00	0.07	-0.02	-0.01			-0.00	0.01	-0.01	0.00

---

‡Except 1952 through 1975 for nonfatal injury rates.

Table 82

Pairwise Correlation Matrix for ST, PMECH, AP, and MACT: Pennsylvania (1950 Through 1975)

	ST	PMECH	AP	MACT
ST	1.0005	-0.42504	-0.71968	-0.54476
PMECH	-0.42504	1.0000	0.47881	0.34301
AP	-0.71968	0.47881	1.0000	0.82182
MACT	-0.54476	0.34301	0.82182	1.0000

Table 83

Pairwise Correlation Matrix for ST, PMECH, AEMPL, and MACT: Pennsylvania (1950 Through 1975)

	ST	PMECH	AEMPL	MACT
ST	1.0005	-0.42504	-0.52232	-0.54476
PMECH	-0.42504	1.0000	0.081817	0.34301
AEMPL	-0.52232	0.081817	1.0000	0.86513
MACT	-0.54476	0.34301	0.86513	1.0000

Table 84

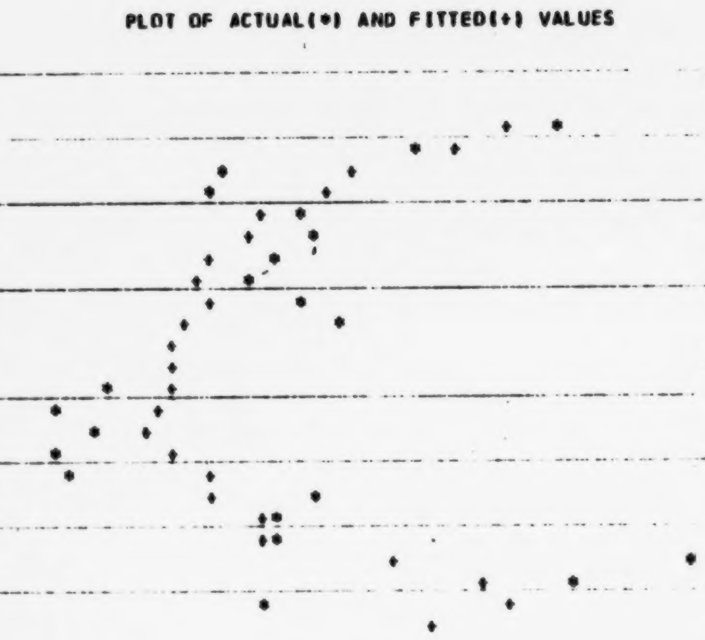
Pairwise Correlation Matrix for ST, PMECH, AP, and MACT: Pennsylvania (1952 Through 1975)

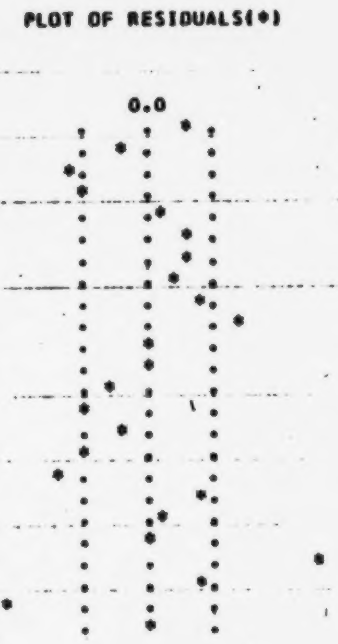
	ST	PMECH	AP	MACT
ST	1.0005	-0.60173	-0.72611	-0.54491
PMECH	-0.60173	1.0000	0.52285	0.37251
AP	-0.72611	0.52285	1.0000	0.81876
MACT	-0.54491	0.37251	0.81876	1.0000

Table 85

Pairwise Correlation Matrix for ST, PMECH, AEMPL, and MACT: Pennsylvania (1952 Through 1975)

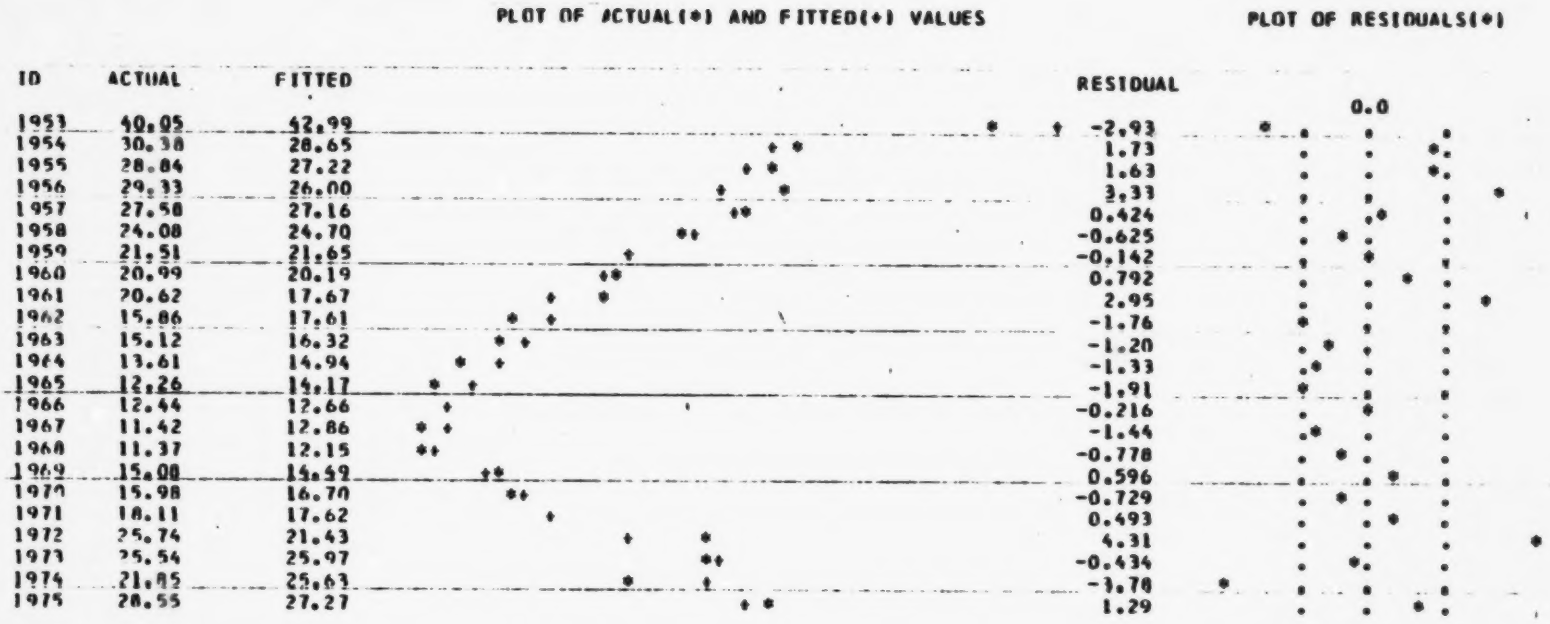
	ST	PMECH	AEMPL	MACT
ST	1.0005	-0.60173	-0.52730	-0.54491
PMECH	-0.60173	1.0000	0.19806	0.37251
AEMPL	-0.52730	0.19806	1.0000	0.88456
MACT	-0.54491	0.37251	0.88456	1.0000


PLOT OF ACTUAL(*) AND FITTED(+) VALUES


PLOT OF RESIDUALS(*)

ID	ACTUAL	FITTED	RESIDUAL
1952	32.72	31.46	1.26
1953	29.51	30.55	-1.04
1954	25.65	28.33	-2.69
1955	25.33	27.67	-2.34
1956	27.09	26.35	0.732
1957	27.48	26.08	1.41
1958	26.55	25.22	1.33
1959	26.15	25.08	1.07
1960	27.05	25.36	1.70
1961	28.03	24.70	3.32
1962	24.43	24.54	-0.106
1963	24.40	24.41	-0.111E-01
1964	23.17	24.50	-1.33
1965	22.02	24.27	-2.26
1966	22.81	23.94	-1.13
1967	22.01	24.39	-2.38
1968	22.16	25.26	-3.09
1969	27.36	25.37	1.98
1970	26.70	26.33	0.371
1971	26.60	26.35	0.251
1972	35.34	29.20	6.14
1973	33.03	31.09	1.94
1974	26.32	31.45	-5.13
1975	29.83	29.82	0.177E-01

Figure 147. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1952 Through 1975: Pennsylvania (OLS)



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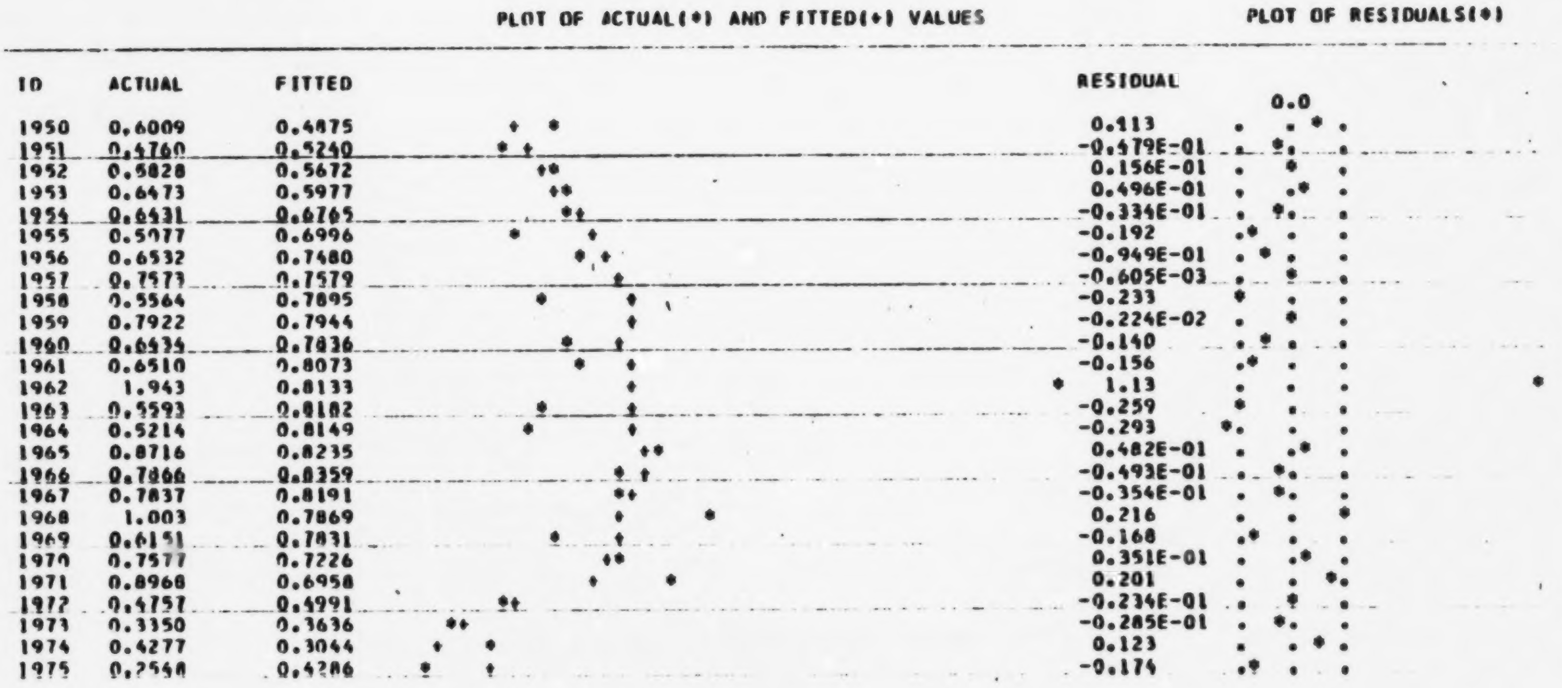
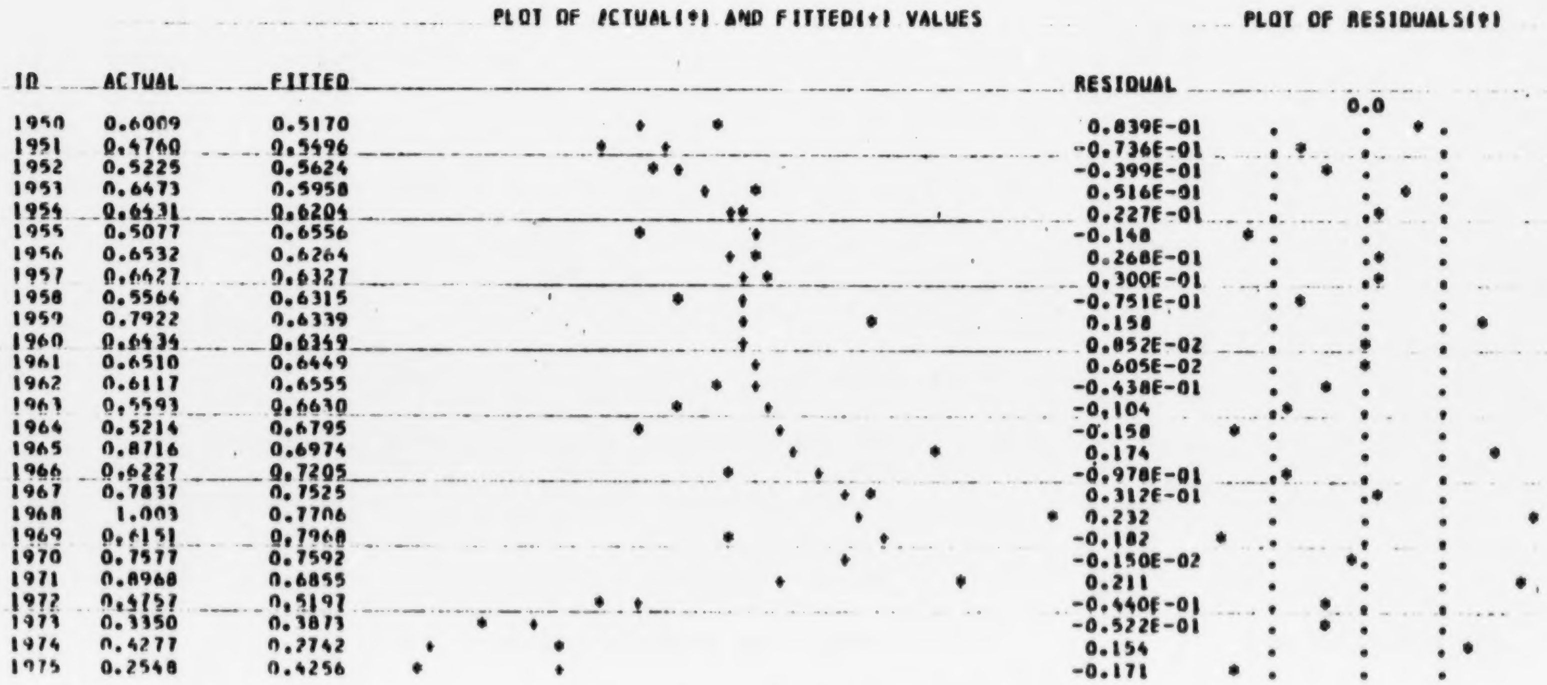
ID      ACTUAL     FITTED     RESIDUAL
1953    40.05      42.99      -2.93
1954    30.38      28.65       1.73
1955    28.84      27.22       1.63
1956    29.33      26.00       3.33
1957    27.58      27.16       0.424
1958    24.08      24.70      -0.625
1959    21.51      21.65      -0.142
1960    20.99      20.19       0.792
1961    20.62      17.67       2.95
1962    15.86      17.61      -1.76
1963    15.12      16.32      -1.20
1964    13.61      14.94      -1.33
1965    12.26      14.17      -1.91
1966    12.44      12.66      -0.216
1967    11.42      12.86      -1.44
1968    11.37      12.15      -0.778
1969    15.00      14.59       0.596
1970    15.98      16.70      -0.729
1971    18.11      17.62       0.493
1972    25.74      21.43       4.31
1973    25.54      25.97      -0.434
1974    21.85      25.63      -3.78
1975    28.55      27.27       1.29
```

Figure 148. Plots for Nonfatal Injury Rate Per Million Tons, 1952 Through 1975: Pennsylvania (CORC)



ID	ACTUAL	FITTED	RESIDUAL
1950	0.6009	0.4875	0.113
1951	0.4760	0.5240	-0.479E-01
1952	0.5828	0.5672	0.156E-01
1953	0.6473	0.5977	0.496E-01
1954	0.6431	0.6765	-0.334E-01
1955	0.5077	0.6996	-0.192
1956	0.6532	0.7480	-0.949E-01
1957	0.7573	0.7579	-0.605E-03
1958	0.5564	0.7895	-0.233
1959	0.7922	0.7944	-0.224E-02
1960	0.6435	0.7836	-0.140
1961	0.6510	0.8073	-0.156
1962	1.943	0.8133	1.13
1963	0.5593	0.8182	-0.259
1964	0.5214	0.8149	-0.293
1965	0.8716	0.8235	0.482E-01
1966	0.7866	0.8359	-0.493E-01
1967	0.7837	0.8191	-0.354E-01
1968	1.003	0.7869	0.216
1969	0.6151	0.7831	-0.168
1970	0.7577	0.7226	0.351E-01
1971	0.8968	0.6958	0.201
1972	0.4757	0.4991	-0.234E-01
1973	0.3350	0.3636	-0.285E-01
1974	0.4277	0.3044	0.123
1975	0.2548	0.4286	-0.174

Figure 149. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1975: Pennsylvania (OLS)



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                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)
ID     ACTUAL     FITTED                                       RESIDUAL
                                                                              0.0
1950   0.6009     0.5170                                        0.839E-01
1951   0.4760     0.5496                                       -0.736E-01
1952   0.5225     0.5624                                       -0.399E-01
1953   0.6473     0.5958                                        0.516E-01
1954   0.6431     0.6204                                        0.227E-01
1955   0.5077     0.6556                                       -0.148
1956   0.6532     0.6264                                        0.268E-01
1957   0.6627     0.6327                                        0.300E-01
1958   0.5564     0.6315                                       -0.751E-01
1959   0.7922     0.6339                                        0.158
1960   0.6434     0.6349                                        0.852E-02
1961   0.6510     0.6449                                        0.605E-02
1962   0.6117     0.6555                                       -0.438E-01
1963   0.5593     0.6630                                       -0.104
1964   0.5214     0.6795                                       -0.158
1965   0.8716     0.6974                                        0.174
1966   0.6227     0.7205                                       -0.978E-01
1967   0.7837     0.7525                                        0.312E-01
1968   1.003      0.7706                                        0.232
1969   0.6151     0.7968                                       -0.182
1970   0.7577     0.7592                                       -0.150E-02
1971   0.8968     0.6855                                        0.211
1972   0.4757     0.5197                                       -0.440E-01
1973   0.3350     0.3873                                       -0.522E-01
1974   0.4277     0.2742                                        0.154
1975   0.2548     0.4256                                       -0.171
```
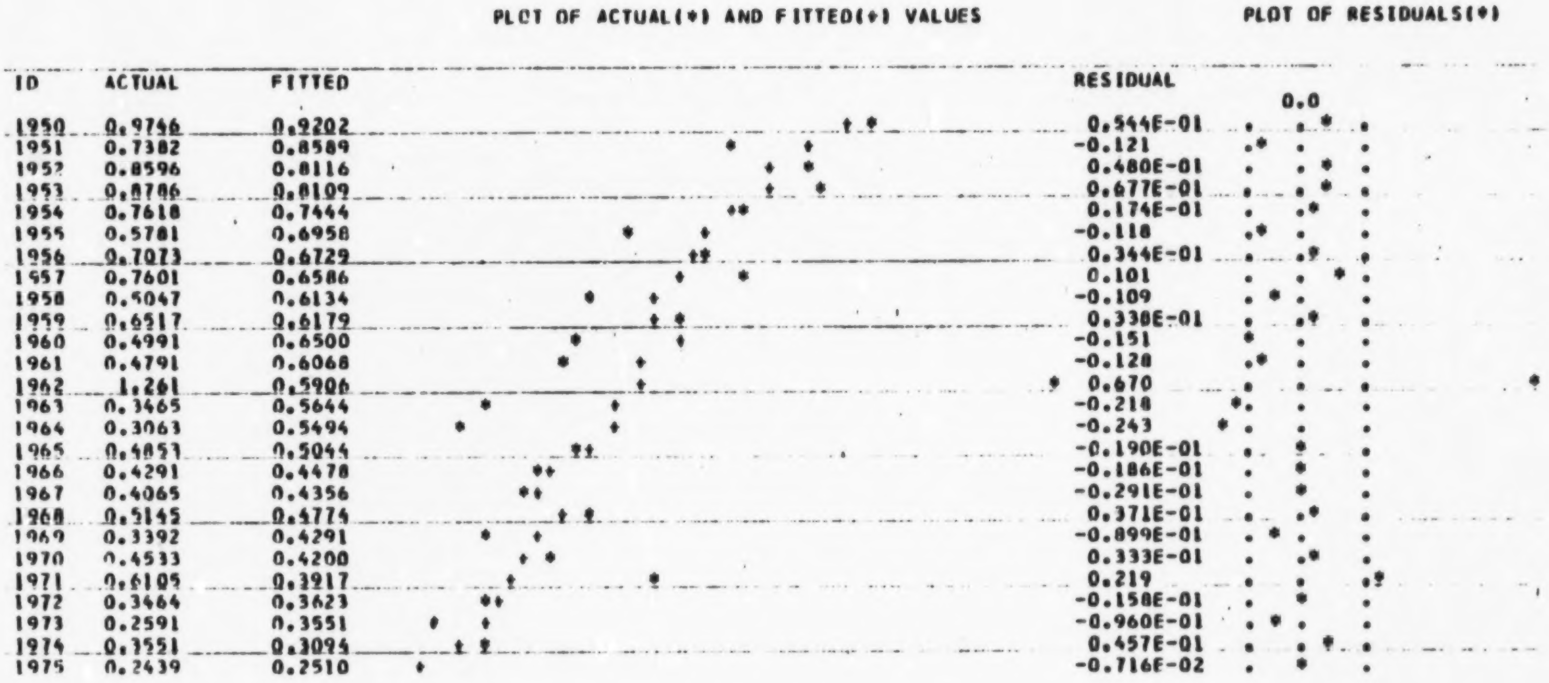
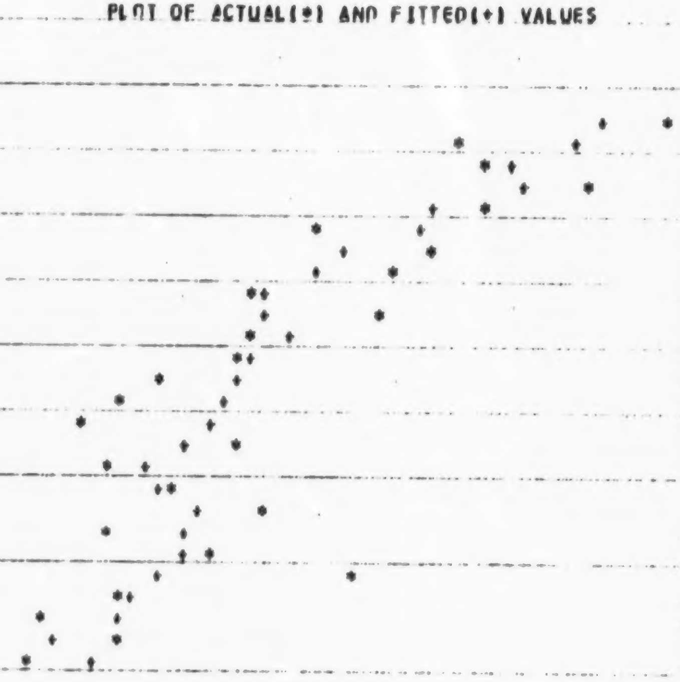

Figure 150. Plots for Fatal Injury Rate Excluding Disasters Per Million Man-Hours, 1950 Through 1975: Pennsylvania (OLS)



```
                          PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)

ID     ACTUAL      FITTED                                       RESIDUAL
                                                                              0.0
1950   0.9746      0.9202                                        0.544E-01
1951   0.7382      0.8589                                       -0.121
1952   0.8596      0.8116                                        0.480E-01
1953   0.8786      0.8109                                        0.677E-01
1954   0.7618      0.7444                                        0.174E-01
1955   0.5781      0.6958                                       -0.118
1956   0.7073      0.6729                                        0.344E-01
1957   0.7601      0.6586                                        0.101
1958   0.5047      0.6134                                       -0.109
1959   0.6517      0.6179                                        0.330E-01
1960   0.4991      0.6500                                       -0.151
1961   0.4791      0.6068                                       -0.128
1962    1.261      0.5906                                        0.670
1963   0.3465      0.5644                                       -0.218
1964   0.3063      0.5494                                       -0.243
1965   0.4853      0.5044                                       -0.190E-01
1966   0.4291      0.4478                                       -0.186E-01
1967   0.4065      0.4356                                       -0.291E-01
1968   0.5145      0.4774                                        0.371E-01
1969   0.3392      0.4291                                       -0.899E-01
1970   0.4533      0.4200                                        0.333E-01
1971   0.6105      0.3917                                        0.219
1972   0.3464      0.3623                                       -0.158E-01
1973   0.2591      0.3551                                       -0.960E-01
1974   0.3551      0.3094                                        0.457E-01
1975   0.2439      0.2510                                       -0.716E-02
```

Figure 151. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1975: Pennsylvania (OLS)

ID	ACTUAL	FITTED	RESIDUAL
1950	0.9746	0.9046	0.700E-01
1951	0.7382	0.8654	-0.127
1952	0.7706	0.8011	-0.305E-01
1953	0.8786	0.8071	0.715E-01
1954	0.7618	0.7072	0.546E-01
1955	0.5781	0.6860	-0.108
1956	0.7073	0.5961	0.111
1957	0.6650	0.5792	0.858E-01
1958	0.5047	0.5160	-0.113E-01
1959	0.6517	0.5135	0.138
1960	0.4991	0.5457	-0.466E-01
1961	0.4791	0.5017	-0.226E-01
1962	0.3970	0.4862	-0.892E-01
1963	0.3465	0.4649	-0.118
1964	0.3063	0.4597	-0.153
1965	0.4853	0.4237	0.616E-01
1966	0.3397	0.3827	-0.430E-01
1967	0.4065	0.3887	0.177E-01
1968	0.5145	0.4449	0.696E-01
1969	0.3392	0.4271	-0.880E-01
1970	0.4533	0.4294	0.239E-01
1971	0.6105	0.3929	0.218
1972	0.3464	0.3593	-0.129E-01
1973	0.2591	0.3420	-0.829E-01
1974	0.3551	0.2743	0.808E-01
1975	0.2439	0.3127	-0.688E-01



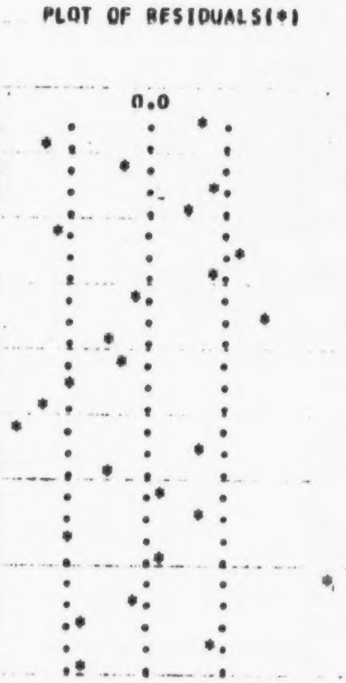


Figure 152. Plots for Fatal Injury Rate Excluding Disasters Per Million Tons, 1950 Through 1975: Pennsylvania (OLS)

explained and one coefficient that is significant (PMECH). The results are again improved by excluding disaster fatalities (Equation 36). Seventy-eight percent of the variance is explained, and three coefficients are significant, including MACT. The coefficients of ST are negative, as expected, in Equations 32, 33, and 34, but are not significant. The only case in which the coefficient of ST is significant, FRPRND, shows an unexpected positive sign. The coefficients of PMECH are negative, as expected, and significant at the 99.0 percent confidence level or greater for all regressions except the fatal injury rates per million man-hours. None of the coefficients of AP are significant. The coefficient of AEMPL is significant only in the regression of NFRPR, and is positive. The coefficients of MACT are negative, as expected, for all regressions except NFRMH. However, they are significant only in the equations for FRMHND (99.5 percent confidence level) and FRPRND (90.0 percent confidence level).

Results of Regressions for 1950 Through 1969 and Predictions of Productivity

In this section, results of regressions on data through 1969 are presented, and predictions of injury rates are made assuming there is no CMHSA. The trends of the independent variables, as discussed previously, suggest that they are not affected by the Mine Act. The results of regressions using data through 1969 are given in Tables 86 and 87. The correlation matrices are presented in Tables 88, 89, 90, and 91. The degree of pairwise correlation is not high. The least satisfactory results are for FRMH, since the equation is not significant at the 95.0 percent confidence level, and only 11.0 percent of the

Table 86

Results of Regressions for Injury Model: Pennsylvania

(1950 Through 1969[*])

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	R^2	S	Auto-correlation (Durbin-Watson statistic)	F-Statistic
37(OLS) NFRMH	52.634 (29.872)	-0.019 (0.402)	-0.299 (0.072) #####	3.503 (9.891)		0.64	1.88	+(1.13)	$8.33_{(3,14)}$
38(CORC) NFRMH	179.956 (70.118)	-0.670 (0.445) #	-1.178 (0.574) ##	22.024 (17.105)		0.60	1.64	None(1.43)	$6.41_{(3,13)}$
39(OLS) NFRPR	71.590 (34.681)	1.019 (0.438) **	-1.258 (0.102) #####		0.027 (0.051)	0.96	2.28	+(1.07)	$112.92_{(3,14)}$
40(CORC) NFRPR	233.192 (81.239)	-0.432 (0.608)	-1.975 (0.525)		0.107 (0.068)	0.96	1.80	+(1.32)	$110.76_{(3,13)}$
41(OLS) FRMH	0.959 (4.344)	-0.016 (0.063)	0.010 (0.007)	-0.772 (1.697)		0.11	0.32	None(2.48)	$0.67^{\#\#}_{(3,16)}$
42(OLS) FRMHND	0.498 (1.633)	-0.005 (0.024)	0.004 (0.003)	0.597 (0.638)		0.26	0.12	None(2.55)	$1.85^{\#\#}_{(3,16)}$

Table 86 (continued)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	R^2	S	Auto-correlation (Durbin-Watson statistic)	F-Statistic
43(CORCO FRMHND	0.381 (1.202)	-0.004 (0.017)	0.005 (0.002) **	0.827 (0.454) *		0.40	0.11	None(2.21)	$3.37_{(3,15)}$
44(OLS) FRPR	-0.975 (2.491)	0.046 (0.035)	-0.014 (0.006) ###		-0.003 (0.004)	0.42	0.20	None(2.56)	$3.92_{(3.16)}$
45(OLS) FRPRND	-0.865 (1.158)	0.040 (0.016) ***	-0.013 (0.003) #####		0.001 (0.002)	0.80	0.09	None(1.98)	$21.39_{(3,16)}$

---

‡ Except 1952 through 1969 for nonfatal injury rates.

‡‡ The equation is not significant at the 95.0 percent confidence level.

Significance Levels:
* Significant at the 90.0 percent confidence level (two-tail test)
** Significant at the 95.0 percent confidence level (two-tail test)
*** Significant at the 98.0 percent confidence level (two-tail test)
# Significant at the 90.0 percent confidence level (one-tail test)
## Significant at the 95.0 percent confidence level (one-tail test)
### Significant at the 97.5 percent confidence level (one-tail test)
##### Significant at the 99.5 percent confidence level (one-tail test)

Table 87

Ninety-Five Percent Confidence Intervals for Coefficients in Pennsylvania Regressions of Injury Model (1950 Through 1969[‡])

Equation Dependent Variable	ST		PMECH		AP		AEMPL	
37(OLS) NFRMH	-0.84	0.88	-0.45	-0.14	-17.71	24.72		
38(CORC) NFRMH	-1.63	0.29	-2.42	0.06	-14.92	58.97		
39(OLS) NFRPR	0.08	1.96	-1.48	-1.04			-0.08	0.14
40(OLS) NFRPR	-1.75	0.88	-3.11	-0.84			-0.04	0.25
41(OLS) FRMH	-0.15	0.12	0.00	0.02	- 4.37	2.83		
42(OLS) FRMHND	-0.06	0.05	-0.00	0.01	- 0.76	1.95		
43(CORC) FRMHND	-0.04	0.03	0.00	0.01	- 0.14	1.79		
44(OLS) FRPR	-0.03	0.12	-0.03	-0.00			-0.01	0.01
45(OLS) FRPRND	0.01	0.07	-0.02	-0.01			-0.00	0.01

[‡] Except 1952 through 1969 for nonfatal injury rates.

Table 88

Pairwise Correlation Matrix for ST, PMECH, and AP: Pennsylvania (1950 Through 1969)

	ST	PMECH	AP
ST	1.0008	-0.25707	-0.53519
PMECH	-0.25707	1.0000	0.29598
AP	-0.53519	0.29598	1.0000

Table 89

Pairwise Correlation Matrix for ST, PMECH, and AEMPL: Pennsylvania (1950 Through 1969)

	ST	PMECH	AEMPL
ST	1.0008	-0.25707	0.075451
PMECH	-0.25707	1.0000	-0.63543
AEMPL	0.075451	-0.63543	1.0000

Table 90

Pairwise Correlation Matrix for ST, PMECH, and AP: Pennsylvania (1952 Through 1969)

	ST	PMECH	AP
ST	1.0008	-0.48819	-0.54918
PMECH	-0.48819	1.0000	0.33188
AP	-0.54918	0.33188	1.0000

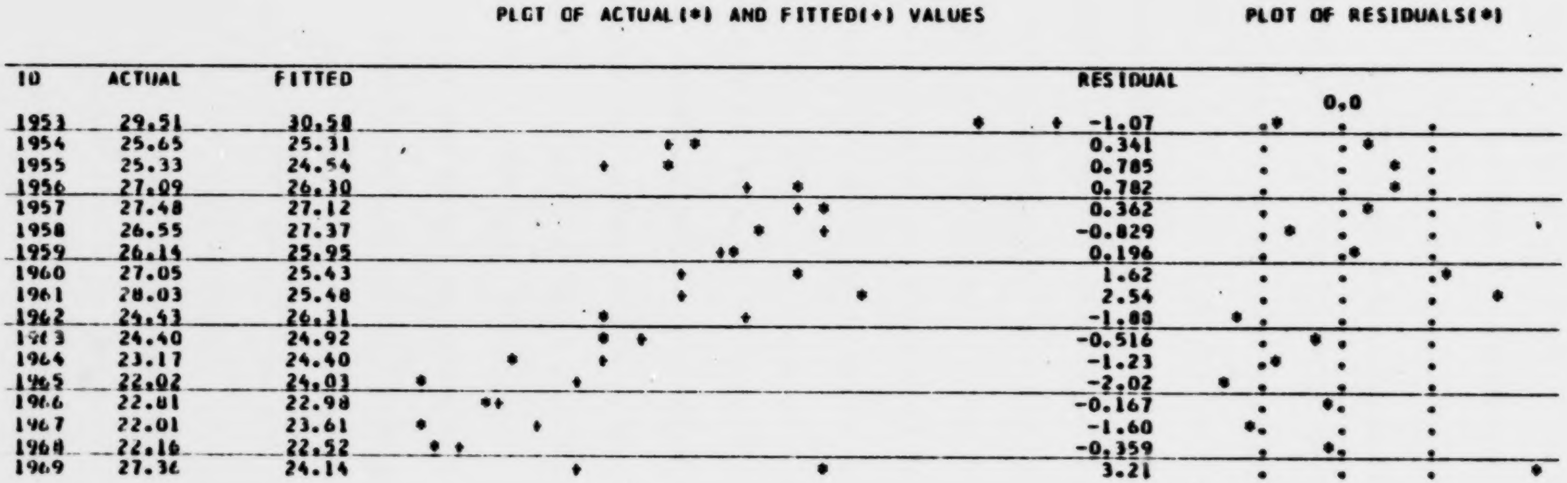
Table 91

Pairwise Correlation Matrix for ST, PMECH, and AEMPL: Pennsylvania (1952 Through 1969)

	ST	PMECH	AEMPL
ST	1.0008	-0.48819	0.12336
PMECH	-0.48819	1.0000	-0.51312
AEMPL	0.12336	-0.51312	1.0000

variance is explained. However, in Equation 43 for FRMHND 40.0 percent of the variance is explained, and Equation 43 is significant. The results for the nonfatal injury rates are good, with 60.0 and 96.0 percent of the variance explained for NFRMH and NFRPR, respectively. However, there is some degree of positive autocorrelation in the regression for NFRPR, even using the Cochrane-Orcutt technique. The regressions for FRPR and FRPRND explain 42.0 and 80.0 percent of the variance, respectively. Appropriate plots are presented in Figures 153 through 158. There is no evidence for heteroskedasticity. The coefficients of ST are negative, as expected, in all regressions except FRPR and FRPRND, and they are significant for NFRMH and FRPRND. The coefficient of PMECH is negative, as expected, in all regressions except for the fatal injury rates. The only case in which the coefficient is unexpectedly positive and significant is FRMHND. The coefficient of AP is positive, in general, but significant only for FRMHND; that of AEMPL is generally positive but not significant.

The regression results were used to extrapolate possible injury rates in 1970 through 1975 in the absence of new federal legislation. These are reported in Table 92. With only one exception (NFRMH in 1974), actual nonfatal injury rates are higher than predicted rates; however, the differences are statistically significant only in 1972. For fatal injury rates per million man-hours, actual rates are lower than predicted except for FRMH in 1970 and 1971 and FRMHND in 1971. These differences are significant only for FRMHND in 1972 through 1975. For FRPR, actual rates exceed predicted rates in all years, but none of these differences are statistically significant. In 1972 through 1975 for FRPRND, actual rates are less than predicted rates, but none of these differences are significant.



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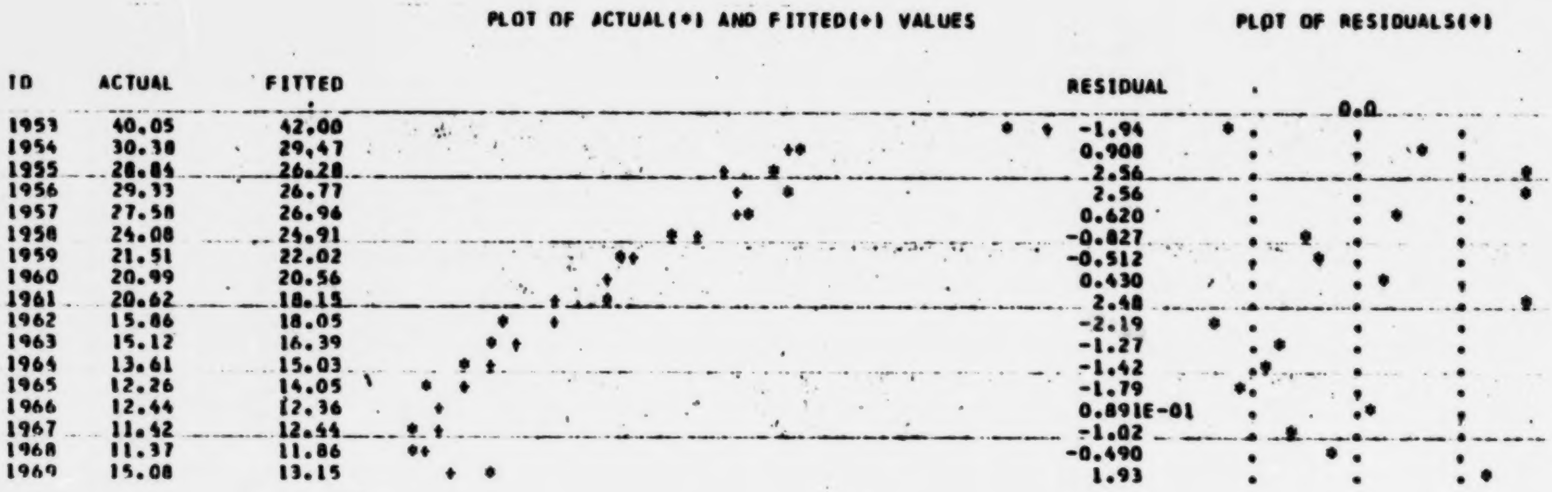
                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)

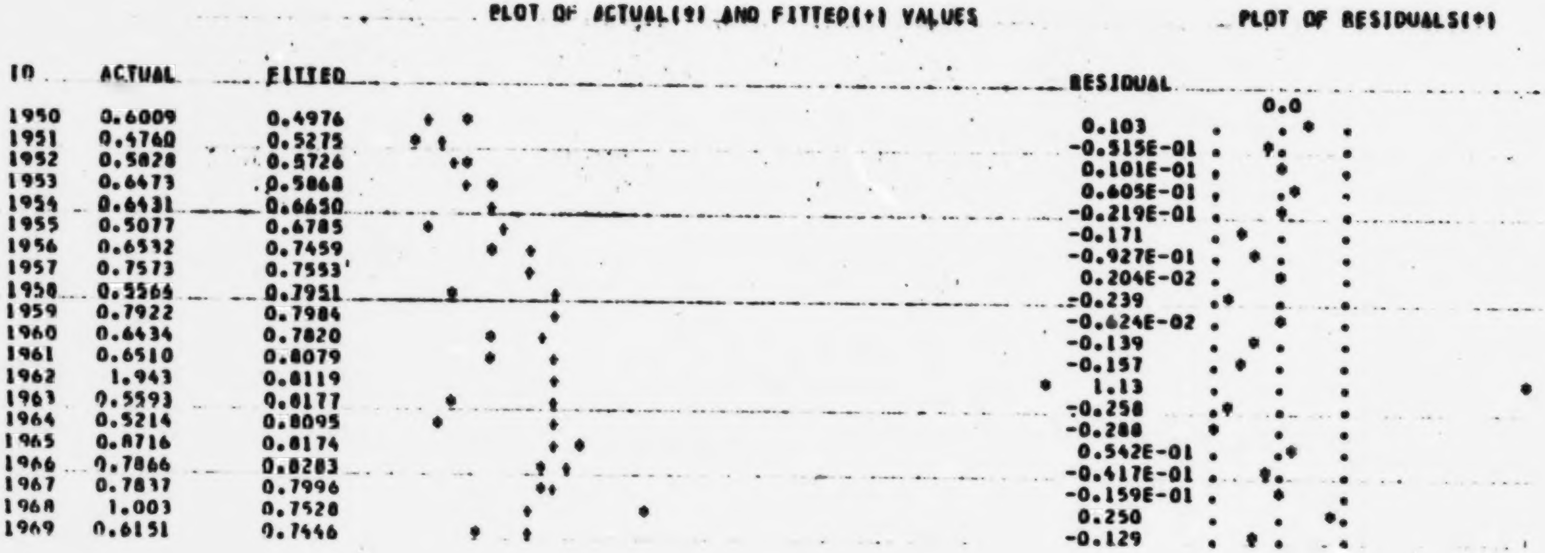
ID      ACTUAL      FITTED                                    RESIDUAL
                                                                                  0.0
1953    29.51       30.58                                     -1.07
1954    25.65       25.31                                      0.341
1955    25.33       24.54                                      0.785
1956    27.09       26.30                                      0.782
1957    27.48       27.12                                      0.362
1958    26.55       27.37                                     -0.829
1959    26.14       25.95                                      0.196
1960    27.05       25.43                                      1.62
1961    28.03       25.48                                      2.54
1962    24.43       26.31                                     -1.88
1963    24.40       24.92                                     -0.516
1964    23.17       24.40                                     -1.23
1965    22.02       24.03                                     -2.02
1966    22.81       22.98                                     -0.167
1967    22.01       23.61                                     -1.60
1968    22.16       22.52                                     -0.359
1969    27.36       24.14                                      3.21
```

Figure 153. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1952 Through 1969: Pennsylvania (CORC)



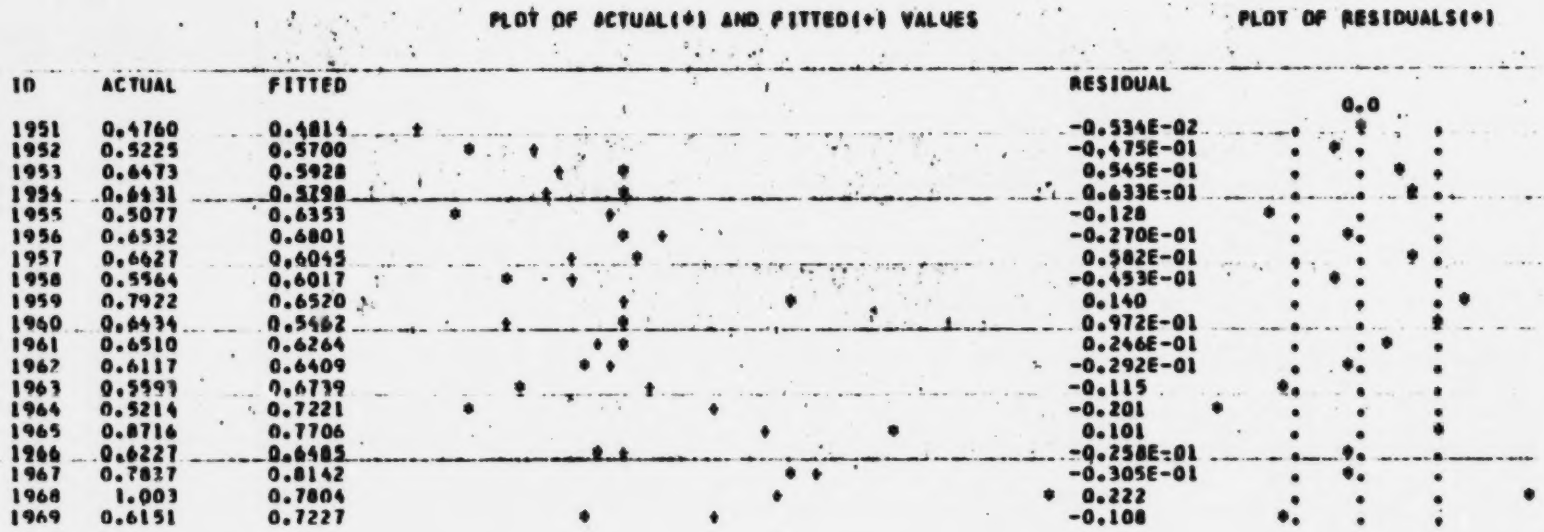
ID	ACTUAL	FITTED	RESIDUAL
1953	40.05	42.00	-1.94
1954	30.38	29.47	0.908
1955	28.84	26.28	2.56
1956	29.33	26.77	2.56
1957	27.58	26.96	0.620
1958	24.08	24.91	-0.827
1959	21.51	22.02	-0.512
1960	20.99	20.56	0.430
1961	20.62	18.15	2.48
1962	15.86	18.05	-2.19
1963	15.12	16.39	-1.27
1964	13.61	15.03	-1.42
1965	12.26	14.05	-1.79
1966	12.44	12.36	0.891E-01
1967	11.42	12.44	-1.02
1968	11.37	11.86	-0.490
1969	15.08	13.15	1.93

Figure 154. Plots for Nonfatal Injury Rate Per Million Tons, 1952 Through 1969: Pennsylvania (CORC)



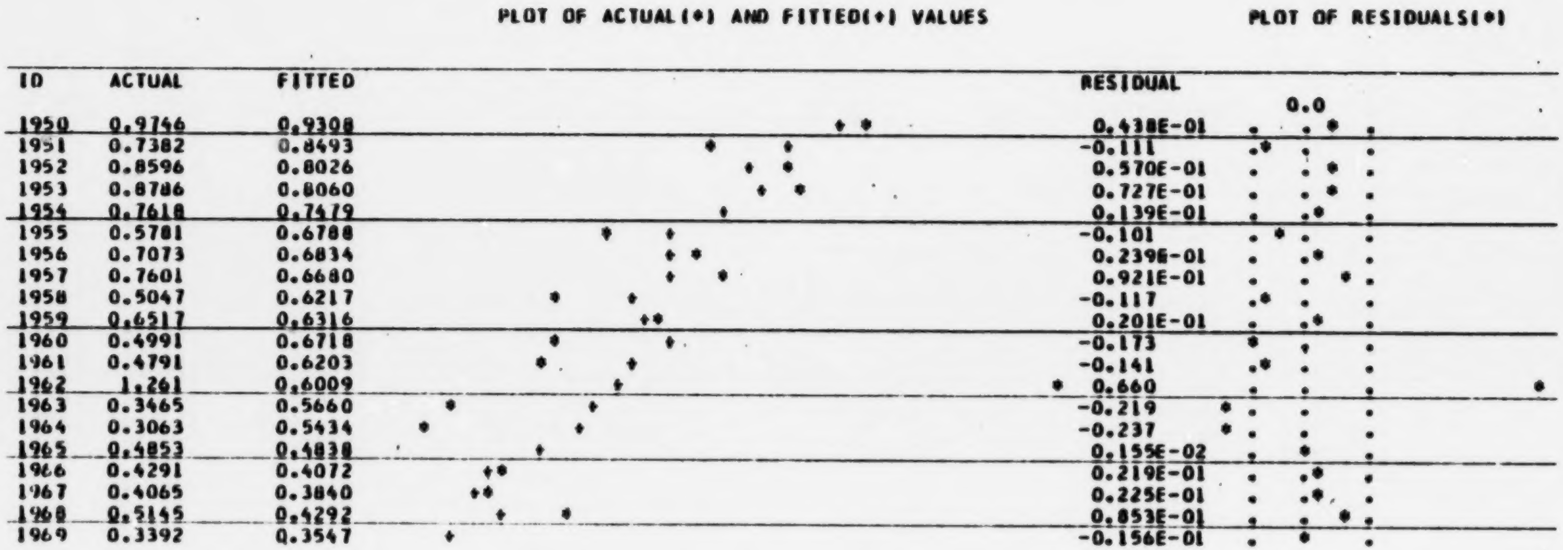
ID	ACTUAL	FITTED	RESIDUAL
1950	0.6009	0.4976	0.103
1951	0.4760	0.5275	-0.515E-01
1952	0.5828	0.5726	0.101E-01
1953	0.6473	0.5868	0.605E-01
1954	0.6431	0.6650	-0.219E-01
1955	0.5077	0.6785	-0.171
1956	0.6532	0.7459	-0.927E-01
1957	0.7573	0.7553	0.204E-02
1958	0.5565	0.7951	-0.239
1959	0.7922	0.7984	-0.624E-02
1960	0.6434	0.7820	-0.139
1961	0.6510	0.8079	-0.157
1962	1.943	0.8119	1.13
1963	0.5593	0.8177	-0.258
1964	0.5214	0.8095	-0.288
1965	0.8716	0.8174	0.542E-01
1966	0.7866	0.8283	-0.417E-01
1967	0.7837	0.7996	-0.159E-01
1968	1.003	0.7528	0.250
1969	0.6151	0.7446	-0.129

Figure 155. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1969: Pennsylvania (OLS)



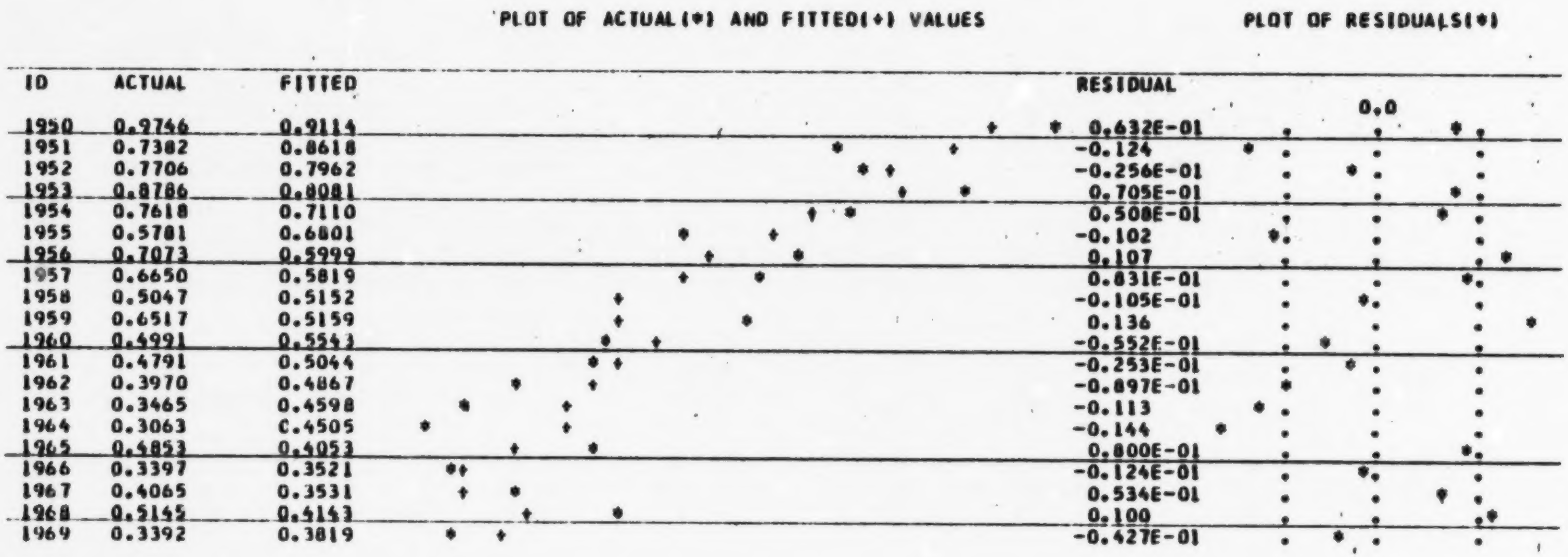
```
ID     ACTUAL     FITTED                RESIDUAL
1951   0.4760     0.4814                -0.534E-02
1952   0.5225     0.5700                -0.475E-01
1953   0.6473     0.5928                 0.545E-01
1954   0.6431     0.5798                 0.633E-01
1955   0.5077     0.6353                -0.128
1956   0.6532     0.6801                -0.270E-01
1957   0.6627     0.6045                 0.582E-01
1958   0.5564     0.6017                -0.453E-01
1959   0.7922     0.6520                 0.140
1960   0.6434     0.5462                 0.972E-01
1961   0.6510     0.6264                 0.246E-01
1962   0.6117     0.6409                -0.292E-01
1963   0.5593     0.6739                -0.115
1964   0.5214     0.7221                -0.201
1965   0.8716     0.7706                 0.101
1966   0.6227     0.6485                -0.258E-01
1967   0.7837     0.8142                -0.305E-01
1968    1.003     0.7804                 0.222
1969   0.6151     0.7227                -0.108
```

Figure 156. Plots for Fatal Injury Rate Excluding Disasters Per Million Man-Hours, 1950 Through 1969: Pennsylvania (CORC)



ID	ACTUAL	FITTED	RESIDUAL
1950	0.9746	0.9308	0.438E-01
1951	0.7382	0.8493	-0.111
1952	0.8596	0.8026	0.570E-01
1953	0.8786	0.8060	0.727E-01
1954	0.7618	0.7479	0.139E-01
1955	0.5781	0.6788	-0.101
1956	0.7073	0.6834	0.239E-01
1957	0.7601	0.6680	0.921E-01
1958	0.5047	0.6217	-0.117
1959	0.6517	0.6316	0.201E-01
1960	0.4991	0.6718	-0.173
1961	0.4791	0.6203	-0.141
1962	1.261	0.6009	0.660
1963	0.3465	0.5660	-0.219
1964	0.3063	0.5434	-0.237
1965	0.4853	0.4838	0.155E-02
1966	0.4291	0.4072	0.219E-01
1967	0.4065	0.3840	0.225E-01
1968	0.5145	0.4292	0.853E-01
1969	0.3392	0.3547	-0.156E-01

Figure 157. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1969: Pennsylvania (OLS)



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                                        PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)

ID     ACTUAL    FITTED                                         RESIDUAL
                                                                               0.0
1950   0.9746    0.9114                                          0.632E-01
1951   0.7382    0.8618                                         -0.124
1952   0.7706    0.7962                                         -0.256E-01
1953   0.8786    0.8081                                          0.705E-01
1954   0.7618    0.7110                                          0.508E-01
1955   0.5781    0.6801                                         -0.102
1956   0.7073    0.5999                                          0.107
1957   0.6650    0.5819                                          0.831E-01
1958   0.5047    0.5152                                         -0.105E-01
1959   0.6517    0.5159                                          0.136
1960   0.4991    0.5543                                         -0.552E-01
1961   0.4791    0.5044                                         -0.253E-01
1962   0.3970    0.4867                                         -0.897E-01
1963   0.3465    0.4598                                         -0.113
1964   0.3063    C.4505                                         -0.144
1965   0.4853    0.4053                                          0.800E-01
1966   0.3397    0.3521                                         -0.124E-01
1967   0.4065    0.3531                                          0.534E-01
1968   0.5145    0.4143                                          0.100
1969   0.3392    0.3819                                         -0.427E-01
```

Figure 158. Plots for Fatal Injury Rate Excluding Disasters Per Million Tons, 1950 Through 1969: Pennsylvania (OLS)

Table 92

Comparison of Predicted Levels of Injury Rates Based on Multiple Regressions With Actual Injury Rates: Pennsylvania‡

Injury Rate		Year					
		1970	1971	1972	1973	1974	1975
NFRMH (CORC)	Predicted	26.08 (±4.80)	26.12 (±4.51)	27.33 (±5.39)	27.62 (±5.98)	27.88 (±5.57)	28.83 (±5.57)
	Actual	26.70	26.60	35.34	33.03	26.32	29.83
NFRPR (CORC)	Predicted	14.90 (±5.62)	15.71 (±5.88)	17.61 (±7.59)	18.70 (±8.81)	19.34 (±9.08)	21.58 (±10.61)
	Actual	15.98	18.11	25.74	25.54	21.85	28.55
FRMH (OLS)	Predicted	0.72 (±0.87)	0.75 (±0.82)	0.69 (±0.96)	0.66 (±1.05)	0.69 (±0.99)	0.71 (±0.99)
	Actual	0.76	0.90	0.48	0.34	0.43	0.26
FRMHND (CORC)	Predicted	0.86 (±0.31)	0.84 (±0.29)	0.90 (±0.35)	0.92 (±0.38)	0.91 (±0.36)	0.91 (±0.36)
	Actual	0.76	0.90	0.48	0.34	0.43	0.26
FRPR (OLS)	Predicted	0.33 (±0.55)	0.30 (±0.57)	0.24 (±0.71)	0.23 (±0.79)	0.17 (±0.82)	0.06 (±0.95)
	Actual	0.45	0.61	0.35	0.26	0.36	0.24
FRPRND (OLS)	Predicted	0.40 (±0.45)	0.38 (±0.46)	0.41 (±0.50)	0.44 (±0.53)	0.40 (±0.54)	0.37 (±0.58)
	Actual	0.45	0.61	0.35	0.26	0.36	0.24

‡ Prediction intervals for a 95.0 percent confidence level are given in parentheses.

The results of the model using data through 1975 were used to make predictions of injury rates without the Mine Act. These predictions are shown in Tables 93 and 94. For NFRMH, actual rates are significantly greater than predicted rates in 1970, 1972, and 1973 (the coefficient of MACT is positive). In all other years, actual rates fall within prediction intervals. Although actual rates for NFRPR are lower than predicted rates in 1970 and 1973 through 1975, none of the differences are significant. For FRMH, actual rates are lower than predicted in 1972 through 1975, but they fall within prediction intervals in all years. Excluding disaster fatalities (FRMHND), actual rates are significantly lower than predicted rates in all years except 1971. For FRPR, actual rates are lower in 1972, 1973, and 1975, but these differences are not significant. However, in 1971 the actual rate is significantly greater than predicted for both FRPR and FRPRND. Although the differences are not statistically significant, actual rates are lower than predicted rates for FRPRND in 1972 through 1975. Tables 93 and 94 also show the percentage decreases in injury rates based on predictions by the model as compared to the predicted rates after eliminating the effects of MACT. For example, in 1975, actual NFRMH is higher than the predicted rate without MACT by 14.6 percent. This is due to the positive coefficient of MACT, not the expected result for that variable. The corresponding comparisons for fatal injury rates, showing the expected influence of MACT, are: actual NFRPR is reduced by 4.5 percent, actual FRMH is reduced by 41.9 percent, actual FRMHND is reduced by 50.0 percent, actual FRPR is reduced by 1.7 percent, and actual FRPRND is reduced by 34.0 percent.

Table 93

Effect of MACT on Nonfatal Injury Rates: Pennsylvania

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT Mean			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
						Low	Mean	High		Low	Mean	High		
						Nonfatal Injuries Per Million Man-Hours								
NFRMH	1969	-0.031	0.097	0.225	0				25.37				27.36	
	1970				5.15924	-1.66	-0.50	0.16	26.33	24.67	25.83	26.49	26.70	-1.9
	1971				10.4678	-2.36	-1.02	0.32	26.35	23.99	25.33	26.67	26.60	-4.0
	1972				29.2330	-6.58	-2.84	0.91	29.20	22.62	26.36	30.11	35.34	-10.8
	1973				42.6833	-9.60	-4.14	1.32	31.09	21.49	26.95	32.41	33.03	-15.4
	1974				52.0947	-16.77	-5.05	1.61	31.45	14.68	26.40	33.06	26.32	-19.1
	1975				39.1479	-8.81	-3.80	1.21	29.82	21.01	26.02	31.03	29.83	-14.6
						Nonfatal Injuries Per Million Tons								
NFRPR	1969	-0.212	-0.033	0.146	0				14.49				15.08	
	1970				5.15924	-0.75	0.17	1.09	16.70	15.95	16.87	17.79	15.98	1.0
	1971				10.4678	-1.53	0.35	2.22	17.62	16.09	17.97	19.84	18.11	1.9
	1972				29.2330	-4.27	0.96	6.20	21.43	17.16	22.39	27.63	25.74	4.3
	1973				42.6833	-6.23	1.41	9.05	25.97	19.74	27.38	35.02	25.54	5.1
	1974				52.0947	-7.61	1.72	11.04	25.63	18.02	27.35	36.67	21.85	6.3
	1975				39.1479	-5.72	1.29	8.30	27.27	21.55	28.56	35.57	28.55	4.5

Table 94

Effect of MACT on Fatal Injury Rates: Pennsylvania

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT	Mean		(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT Low -((1) x (2))	Mean	High	(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT Low (3) + (4)	Mean	High	(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
						Fatal Injuries Per Million Man-Hours								
FRMH	1969	-0.023	-0.008	0.007	0				0.78				0.62	
	1970				5.15924	-0.04	0.04	0.12	0.72	0.68	0.76	0.84	0.76	5.3
	1971				10.4678	-0.07	0.08	0.24	0.70	0.63	0.78	0.94	0.90	10.3
	1972				29.2330	-0.20	0.23	0.67	0.50	0.30	0.73	1.17	0.48	31.5
	1973				42.6833	-0.30	0.34	0.98	0.36	0.06	0.70	1.34	0.34	48.6
	1974				52.0947	-0.36	0.42	1.20	0.30	--	0.72	1.50	0.43	58.3
	1975				39.1479	-0.27	0.31	0.90	0.43	0.16	0.74	1.33	0.25	41.9
						Fatal Injuries Excluding Disasters Per Million Man-Hours								
FRMHND	1969	-0.017	-0.011	-0.005	0				0.80				0.62	
	1970				5.15924	0.03	0.06	0.09	0.76	0.79	0.82	0.85	0.76	7.3
	1971				10.4678	0.05	0.12	0.18	0.69	0.74	0.81	0.87	0.90	14.8
	1972				29.2330	0.15	0.32	0.50	0.52	0.67	0.84	1.02	0.48	38.1
	1973				42.6833	0.21	0.47	0.73	0.39	0.60	0.86	1.12	0.34	54.7
	1974				52.0947	0.26	0.57	0.89	0.27	0.53	0.84	1.17	0.43	67.9
	1975				39.1479	0.20	0.43	0.67	0.43	0.63	0.86	1.10	0.25	50.0
						Fatal Injuries Per Million Tons								
FRPK	1969	-0.013	-0.001	0.011	0				0.43				0.34	
	1970				5.15924	-0.06	0.01	0.07	0.42	0.36	0.43	0.49	0.45	2.3
	1971				10.4678	-0.12	0.01	0.14	0.39	0.27	0.40	0.53	0.61	2.5
	1972				29.2330	-0.32	0.03	0.38	0.36	0.04	0.39	0.74	0.35	7.7
	1973				42.6833	-0.47	0.04	0.55	0.36	--	0.40	0.91	0.26	10.0
	1974				52.0947	-0.57	0.05	0.68	0.31	--	0.36	0.99	0.36	13.9
	1975				39.1479	-0.43	0.04	0.51	0.25	--	0.29	0.76	0.24	1.7

Table 94 (Continued)

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Fatal Injuries Excluding Disasters Per Million Tons								
FRPRND	1969	-0.010	-0.004	0.002	0				0.43				0.34	
	1970				5.15924	-0.01	0.02	0.05	0.43	0.42	0.45	0.48	0.45	4.4
	1971				10.4678	-0.02	0.04	0.10	0.39	0.37	0.43	0.49	0.61	9.3
	1972				29.2330	-0.06	0.12	0.29	0.36	0.30	0.48	0.65	0.35	25.0
	1973				42.6833	-0.09	0.17	0.43	0.34	0.25	0.51	0.77	0.26	33.3
	1974				52.0947	-0.10	0.21	0.52	0.27	0.17	0.48	0.79	0.36	43.8
	1975				39.1479	-0.08	0.16	0.39	0.31	0.23	0.47	0.70	0.24	34.0

Summary

The relationships of the independent variables to the injury rates may be summarized as follows. For NFRMH: (1) weighted-average seam thickness is positively related and not significant; (2) percent mechanically loaded is negatively related and significant; (3) average production is positively related and not significant; and (4) the Mine-Act variable is positively related and not significant. For NFRPR: (1) weighted-average seam thickness is negatively related but not significant; (2) percent mechanically loaded is negatively related and significant; (3) weighted-average employment is positively related and significant; and (4) the Mine-Act variable is negatively related but not significant. For FRMH: (1) weighted-average seam thickness is negatively related but not significant; (2) percent mechanically loaded is positively related and not significant; (3) average production is negatively related but not significant; and (4) the Mine-Act variable is negatively related but not significant. For FRMHND: (1) weighted-average seam thickness is negatively related but not significant; (2) percent mechanically loaded is positively related and not significant; (3) average production is positively related and not significant; and (4) the Mine-Act variable is negatively related and significant. For FRPR: (1) weighted-average seam thickness is positively related and not significant; (2) percent mechanically loaded is negatively related and significant; (3) weighted-average employment is negatively related but not significant; and (4) the Mine-Act variable is negatively related but not significant. For FRPRND: (1) weighted-average seam thickness is positively related and significant; (2) percent mechanically loaded is negatively related and significant; (3) weighted-average employment is positively related and not significant; and (4) the Mine-Act variable is negatively related and significant.

The effects of each independent variable on the injury rates may be summarized as follows: (1) an increase in ST of one inch increases NFRMH by 0.31, decreases NFRPR by 0.72, decreases FRMH by 0.01, decreases FRMHND by 0.004, increases FRPR by 0.04, and increases FRPRND by 0.03; (2) an increase in PMECH of one percent decreases NFRMH by 0.29, decreases NFRPR by 2.26, increases FRMH by 0.01, increases FRMHND by 0.005, decreases FRPR by 0.01, and decreases FRPRND by 0.01; (3) an increase in AP of one million tons increases NFRMH by 14.11, decreases FRMH by 0.52, and increases FRMHND by 0.67; (4) an increase in AEMPL of ten increases NFRPR by 2.0, decreases FRPR by 0.01, and increases FRPRND by 0.02; and (5) an increase in the value of the Mine-Act variable of one increases NFRMH by 0.1, decreases NFRPR by 0.03, decreases FRMH by 0.01, decreases FRMHND by 0.01, decreases FRPR by 0.001, and decreases FRPRND by 0.004.

The results suggest that the Mine Act may have reduced fatal injury rates (especially excluding disasters) but not nonfatal injury rates.

Illinois

Data and Trends of Variables

The data used for Illinois are presented in Table 95. The state data on injuries, total production and average production, man-days worked, weighted-average seam thickness, and weighted-average employment were obtained from the Illinois Annual Coal, Oil, and Gas Reports for the years 1950 through 1975. Data are complete only for shipping mines (those mines selling coal outside the local area); therefore, local mines are not included in the data set. Other data sources are as given in the section on methods of investigation. There does not appear to be a problem in the injury data for 1950 through 1952 as discussed in the productivity chapter. It does not seem to be badly out of trend with data for later years, as productivity obviously is, and will be seen in the presentation of trends of the variables. Thus, these years are used for the regressions.

The trends over time of the accident rates studied are shown in Figures 159 through 164. Nonfatal injury rates per million man-hours (NFRMH) show a downward trend from 1950 to 1960, approximately, then an upward trend to around 1969, followed by a downward trend (Figure 159). Piecewise regression results (Table 96) show that these breaks in trend in 1960 and 1969 are significant at the 99.0 percent confidence level. Nonfatal injury rates per million tons (NFRPR) follow a similar pattern, although the second break in trend in 1969 to slightly declining rates is not as pronounced (Figure 160). A piecewise regression reveals that breaks in trend in 1960 and 1969 are significant at confidence levels of 99.0 and 95.0 percent, respectively (Table 96). Fatal injury

Table 95

Data for Illinois Injury Model

Year	Number of Nonfatal Injuries NFTL	Nonfatal Injury Rate Per Million Man-Hours NFRMH	Nonfatal Injury Rate Per Million Tons NFRPK	Total Number of Fatal Injuries FTL	Number of Disaster Fatalities DFTL	Fatal Injury Rate Per Million Man-Hours FRMH	Fatal Injury Rate Excluding Disaster Fatalities Per Million Man-Hours FRMHND
1950	1450	59.6299	38.2703	39	0	1.60384	1.60384
1951	1281	64.7023	36.2837	149	119	7.52588	1.51528
1952	976	50.5634	34.9403	26	0	1.34698	1.34698
1953	753	37.7653	26.5594	26	0	1.30398	1.30398
1954	575	35.3101	23.3458	16	0	0.982542	0.982542
1955	524	33.8354	19.8899	17	0	1.09771	1.09771
1956	540	35.1258	19.6382	17	0	1.10581	1.10581
1957	425	31.3889	16.2878	19	0	1.40327	1.40327
1958	346	28.0965	15.3517	6	0	0.487223	0.487223
1959	365	31.0564	15.8812	5	0	0.425430	0.425430
1960	256	23.5463	11.2496	4	0	0.367911	0.367911
1961	236	25.0608	10.8128	4	0	0.424759	0.424759
1962	262	28.0677	11.5011	17	11	1.82119	0.642772
1963	301	31.7318	12.9846	12	0	1.26506	1.26506
1964	314	32.2581	13.0700	6	0	0.616397	0.616397
1965	345	34.2829	13.9465	8	0	0.794965	0.794965
1966	369	36.3749	14.4507	4	0	0.394308	0.394308
1967	369	36.7796	14.3611	10	0	0.996736	0.996736
1968	348	36.7039	14.7911	13	0	1.37112	1.37112
1969	420	36.4002	13.9199	5	0	0.433335	0.433335
1970	479	37.6396	15.1508	9	0	0.707217	0.707217
1971	428	31.3996	14.5312	14	0	1.02709	1.02709
1972	509	32.7730	16.0488	9	0	0.579483	0.579483
1973	392	25.9312	12.0329	3	0	0.198453	0.198453
1974	379	24.4187	12.1849	9	0	0.579865	0.579865
1975	490	27.2977	15.3701	6	0	0.334258	0.334258

Table 95 (Continued)

Year	Fatal Injury Rate Per Million Tons FRPR	Fatal Injury Rate Excluding Disaster Fatalities Per Million Tons FRPRND	Total Production TPROD X 10^{-6} (millions of short tons)	Number of Man-Days Worked MNDY X 10^{-6} (millions of man-days)	Weighted-Average Seam Thickness ST (feet)	Percent of Coal Loaded Mechanically PMECH	Weighted-Average Employment AEMPL	Average Production AP X 10^{6} (short tons)	Number of Inspections Per Mine Under CMHSA MACT
1950	1.02934	1.02934	37.8884	3.03958	7.31	96.01	248	344440	0.0
1951	4.22035	0.849735	35.3051	2.47479	7.37	96.72	239	333067	0.0
1952	0.930786	0.930786	27.9334	2.41281	7.29	97.21	236	332540	0.0
1953	0.917057	0.917057	28.3516	2.49236	7.27	98.76	229	416935	0.0
1954	0.649622	0.649622	24.6297	2.03554	7.35	99.19	222	410495	0.0
1955	0.645282	0.645282	26.3451	1.93584	7.27	99.34	215	516570	0.0
1956	0.618241	0.618241	27.4974	1.92167	7.30	99.50	211	597769	0.0
1957	0.728163	0.728163	26.0931	1.69248	7.41	99.49	216	606816	0.0
1958	0.266215	0.266215	22.5382	1.53934	7.64	99.63	211	609140	0.0
1959	0.217550	0.217550	22.9832	1.46910	7.62	99.81	210	589313	0.0
1960	0.175775	0.175775	22.7564	1.35903	7.50	99.81	187	598853	0.0
1961	0.183267	0.183267	21.8260	1.17714	7.48	99.80	195	704066	0.0
1962	0.746252	0.263383	22.7805	1.16682	7.48	100.0	201	843723	0.0
1963	0.517659	0.517659	23.1813	1.18572	7.49	100.0	211	927252	0.0
1964	0.249745	0.249745	24.0245	1.21675	7.52	100.0	221	858018	0.0
1965	0.323397	0.323397	24.7374	1.25792	7.55	100.0	239	1030730	0.0
1966	0.156647	0.156647	25.5351	1.26804	7.62	100.0	276	1215960	0.0
1967	0.389191	0.389191	25.6943	1.25409	7.60	100.0	267	1284720	0.0
1968	0.552540	0.552540	23.5277	1.18516	7.66	100.0	266	1022950	0.0
1969	0.165713	0.165713	30.1726	1.44230	7.44	100.0	245	1077590	0.0
1970	0.284670	0.284670	31.6156	1.59074	7.39	99.99	256	1090190	5.15924
1971	0.475319	0.475319	29.4539	1.70385	7.37	100.0	270	1090890	10.4678
1972	0.283771	0.283771	31.7158	1.94138	7.37	100.0	329	1219840	29.2330
1973	0.0920886	0.0920886	32.5773	1.88962	7.28	100.0	368	1357390	42.6833
1974	0.289351	0.289351	31.1041	1.94011	7.31	100.0	393	1352350	52.0947
1975	0.188205	0.188205	31.8800	2.24378	7.28	100.0	458	1518100	39.1479

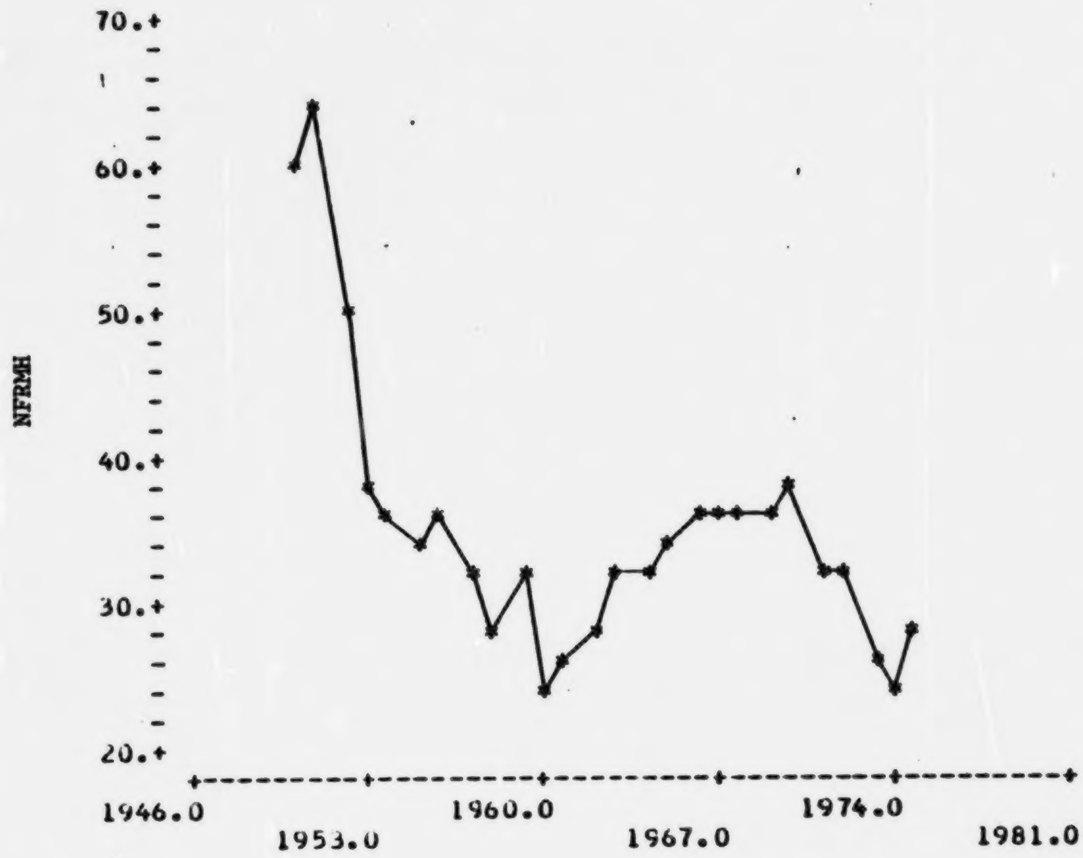


Figure 159. Trend of Nonfatal Injury Rate Per Million Man-Hours: Illinois (1950 Through 1975)

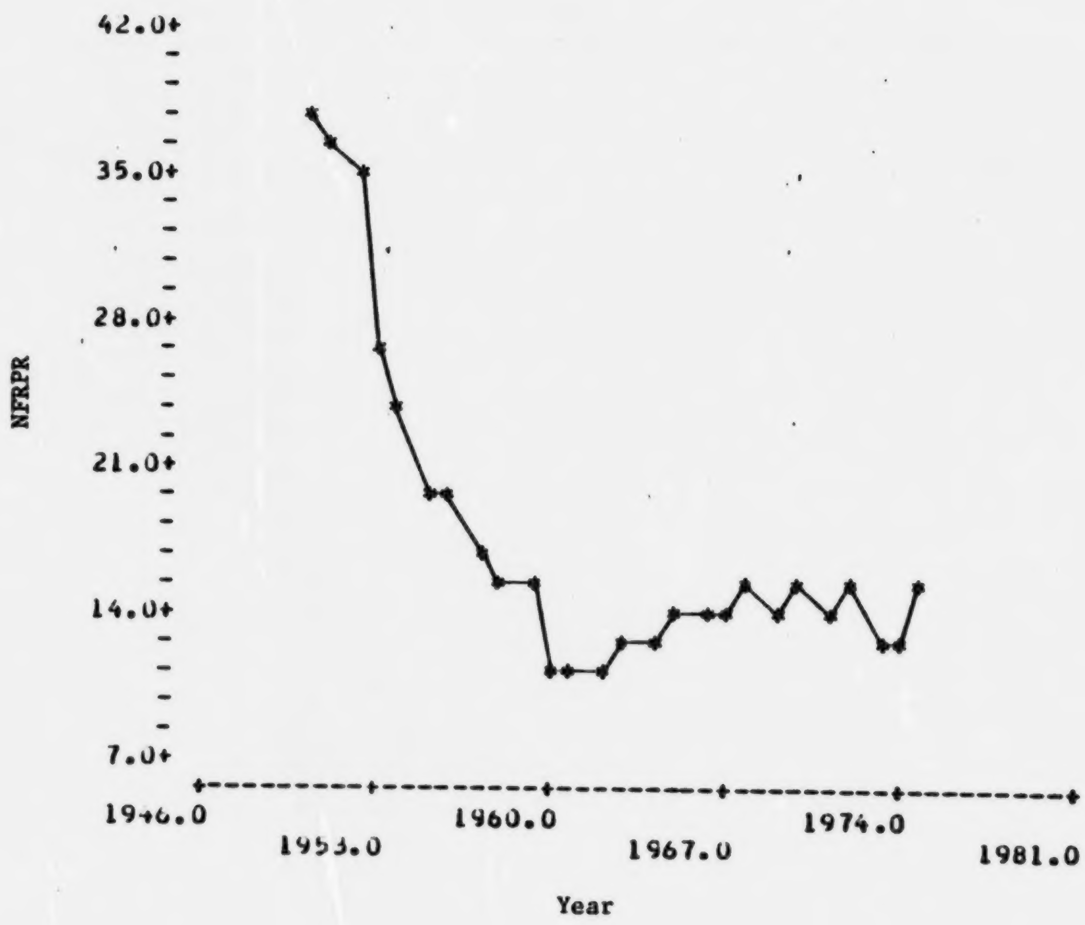


Figure 160. Trend of Nonfatal Injury Rate Per Million Tons: Illinois (1950 Through 1975)

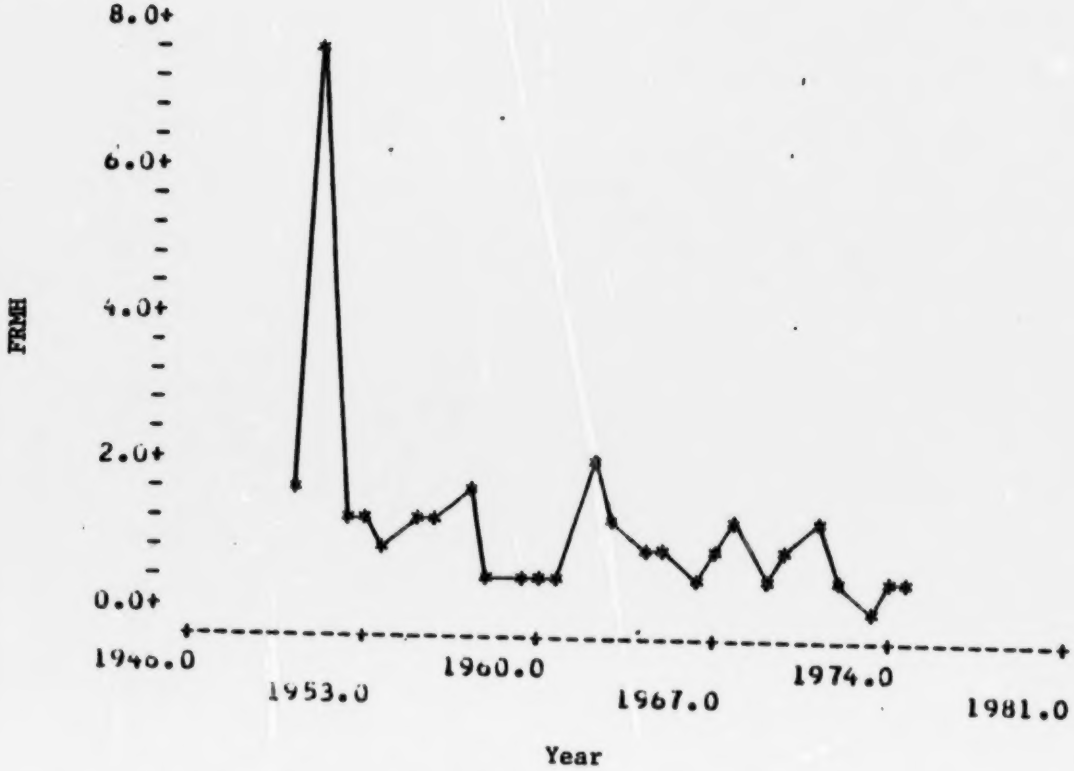


Figure 161. Trend of Fatal Injury Rate Per Million Man-Hours: Illinois (1950 Through 1975)

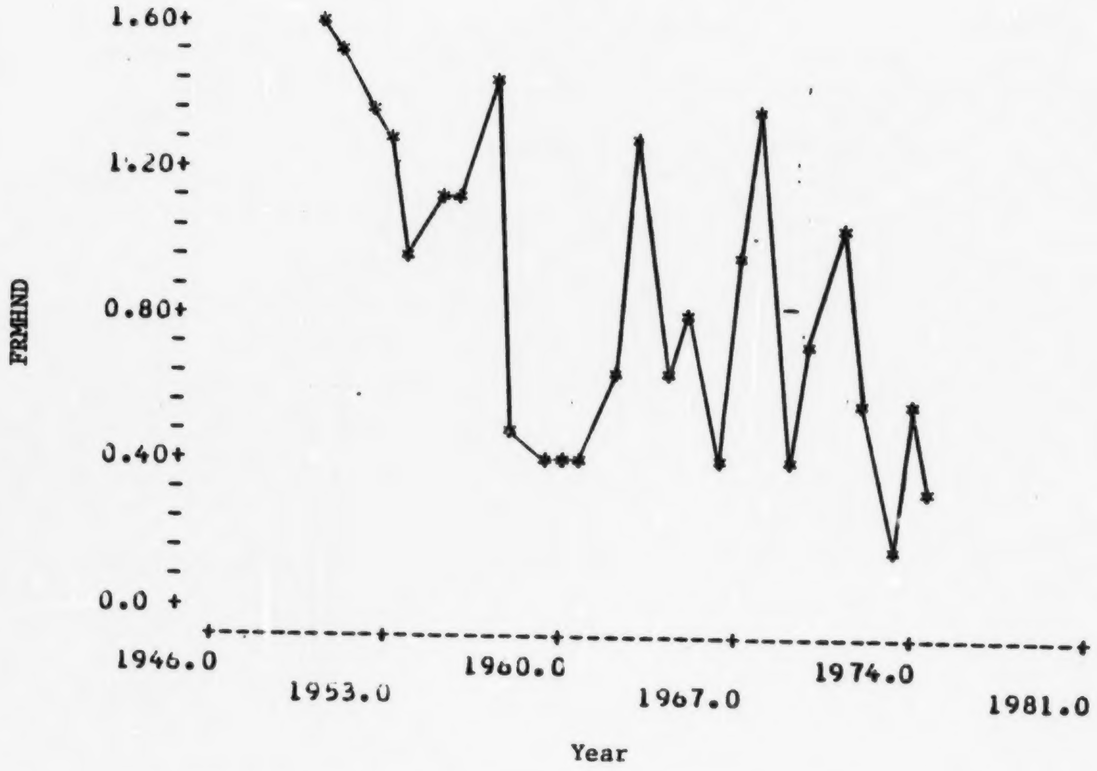


Figure 162. Trend of Fatal Injury Rate Excluding Disasters Per Million Man-Hours: Illinois (1950 Through 1975)

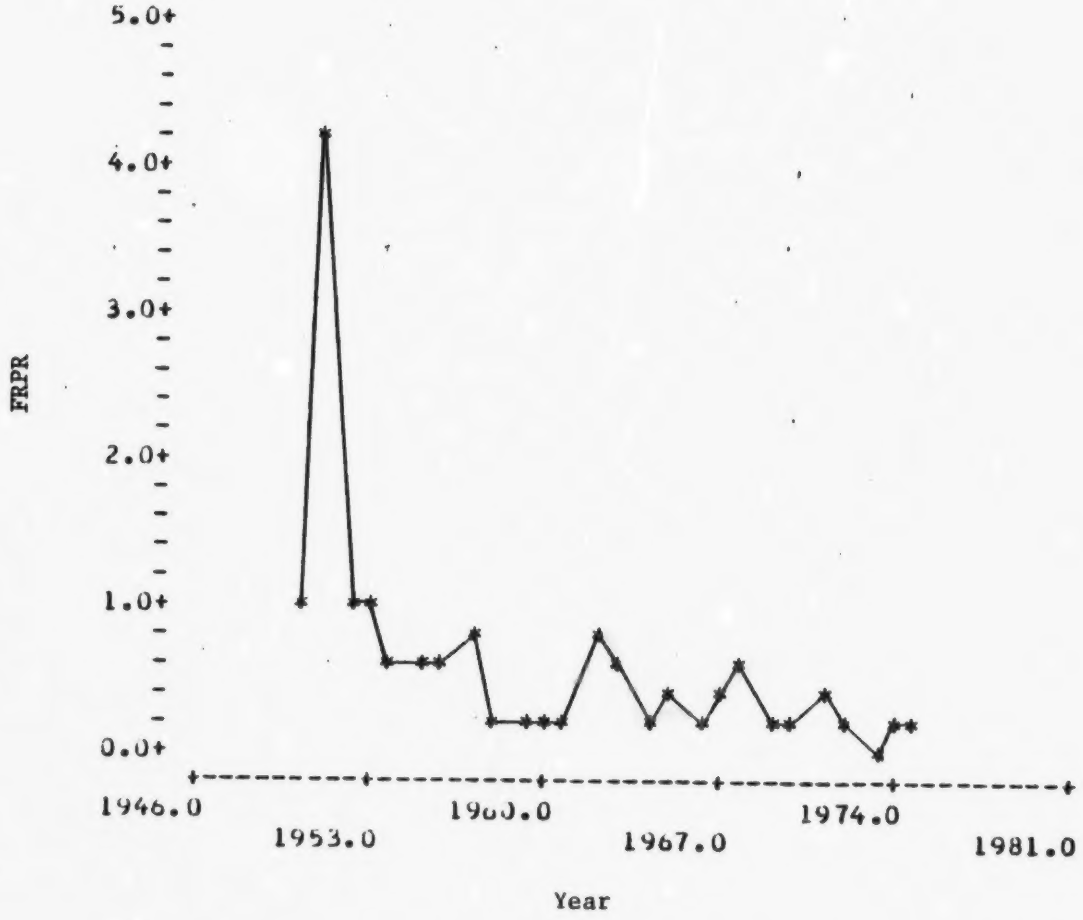


Figure 163. Trend of Fatal Injury Rate Per Million Tons: Illinois (1950 Through 1975)

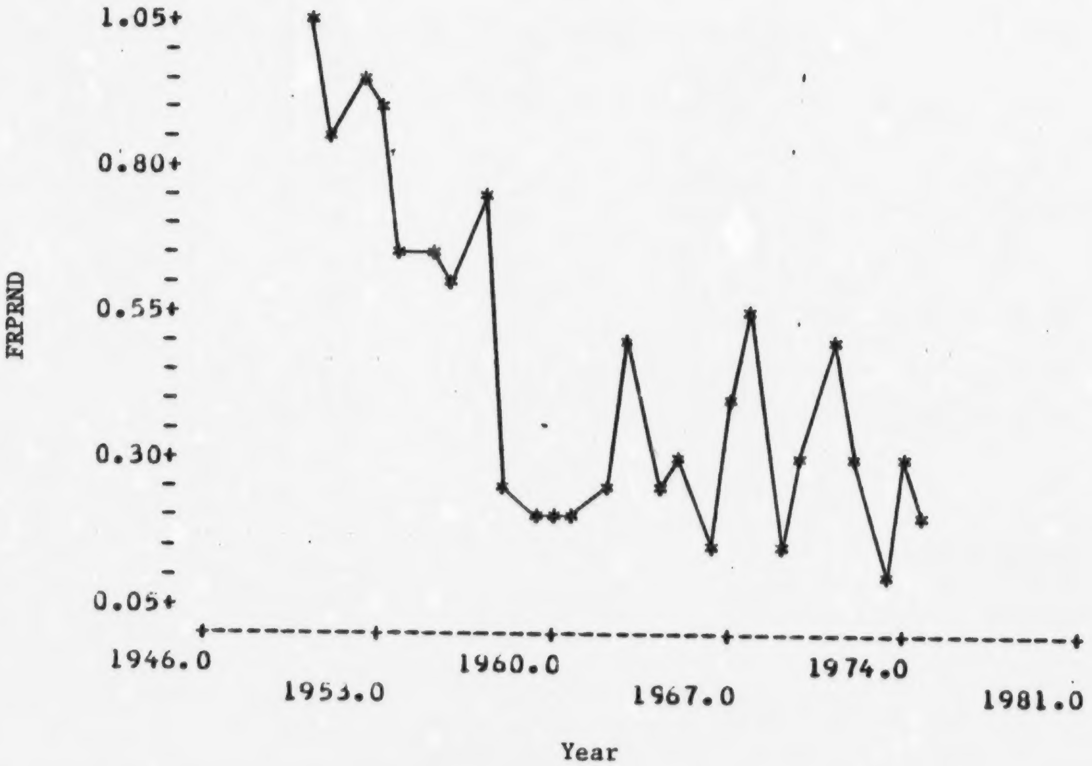


Figure 164. Trend of Fatal Injury Rate Excluding Disasters Per Million Tons: Illinois (1950 Through 1975)

Table 96

Piecewise Regression Results for Injury Rates: Illinois

Equation Dependent Variable	Constant	X_1	$X_2(X_1-11)$ Join Point of 1960	$X_3(X_1-20)$ Join Point of 1969	R^2	S	F-statistic
46 NFRMH	59.64 (2.68)	-3.32 (0.35) ****	5.13 (0.64) ****	-4.445 (0.927) ****	0.83	4.36	$34.80_{(3,22)}$
47 NFRPR	39.49 (1.16)	-2.65 (0.15) ****	3.21 (0.28) ****	-0.88 (0.40) **	0.95	1.88	$134.64_{(3,22)}$
48 FRMH	3.36 (0.74)	-0.27 (0.10) ***	0.35 (0.18) *	-0.20 (0.26)	0.33	1.20	$3.67_{(3,22)}$
49 FRMHND	1.72 (0.18)	-0.11 (0.02) ****	0.15 (0.04) ****	-0.14 (0.06)	0.60	0.29	$10.86_{(3,22)}$
50 FRPR	2.07 (0.39)	-0.18 (0.05) ****	0.21 (0.09) **	-0.08 (0.13)	0.44	0.63	$5.77_{(3,22)}$
51 FRPRND	1.13 (0.08)	-0.08 (0.01) ****	0.10 (0.02) ****	-0.04 (0.03)	0.81	0.13	$31.12_{(3,22)}$

Significance Levels:
* Significant at the 90.0 percent confidence level (two-tail test)
** Significant at the 95.0 percent confidence level (two-tail test)
*** Significant at the 98.0 percent confidence level (two-tail test)
**** Significant at the 99.0 percent confidence level (two-tail test)

rates per million man-hours (FRMH) show a general downward trend overall with outliers for disaster years, 1951 and 1962 (Figure 161). Piecewise regression reveals no significant break in trend in 1969. Before 1960 to 1961 the trend is one of declining rates, in general; thereafter, there is some rise to 1969. This change in trend in 1960 is significant at a 90.0 percent confidence level (Table 96). The fatal injury rate excluding disasters per million man-hours (FRMHND) has an overall declining trend, with breaks in trend in 1960 and 1969 (Figure 162) that are significant at the 99.0 and 95.0 percent confidence levels, respectively (Table 96). Thus, the overall trend is for generally decreasing rates to 1960, a general rise to around 1969, then a fall in rates occurs. The trend for fatal injury rates per million tons (FRPR) produced is quite similar to that for the rate per million man-hours. The trend through time is for decreasing fatality rates. There is a significant break in trend in 1960 (95.0 percent confidence level), with declining rates before 1960 and increasing rates after 1960 (Table 96). Of course, the outlier in 1951 is very influential in this trend. Fatal injury rates excluding disasters per million tons (FRPRND) have an overall downward trend with, again, a significant break from decreasing to increasing values in 1960 (Table 96). This break in trend is significant at the 99.0 percent confidence level.

The trends for weighted-average seam thickness and average production (Figures 41 and 40) have been described in the section on Illinois in Chapter III. Percent of coal loaded mechanically rises steeply from around 96.0 percent in 1950 to 100.0 percent in 1962 where it remains (Figure 165). Weighted-average employment shows a downward trend from 1950 to around 1960, then upward through 1975 (Figure 166).

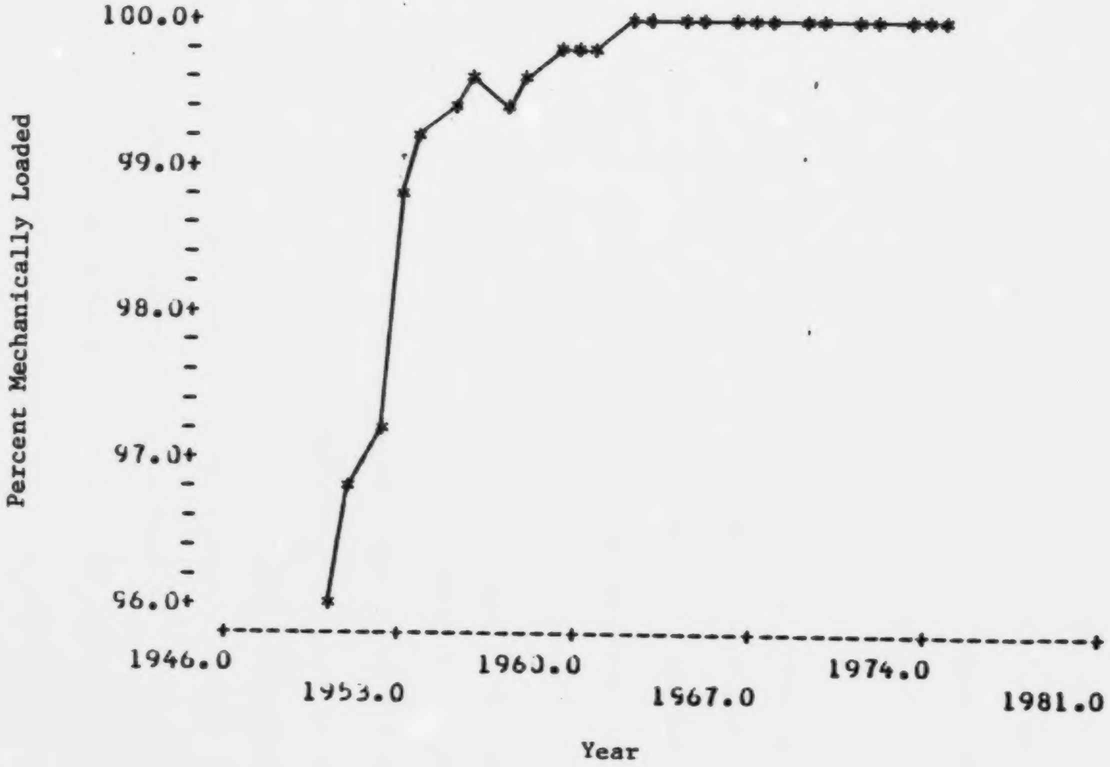


Figure 165. Trend of Percent Mechanically Loaded: Illinois (1950 Through 1975)

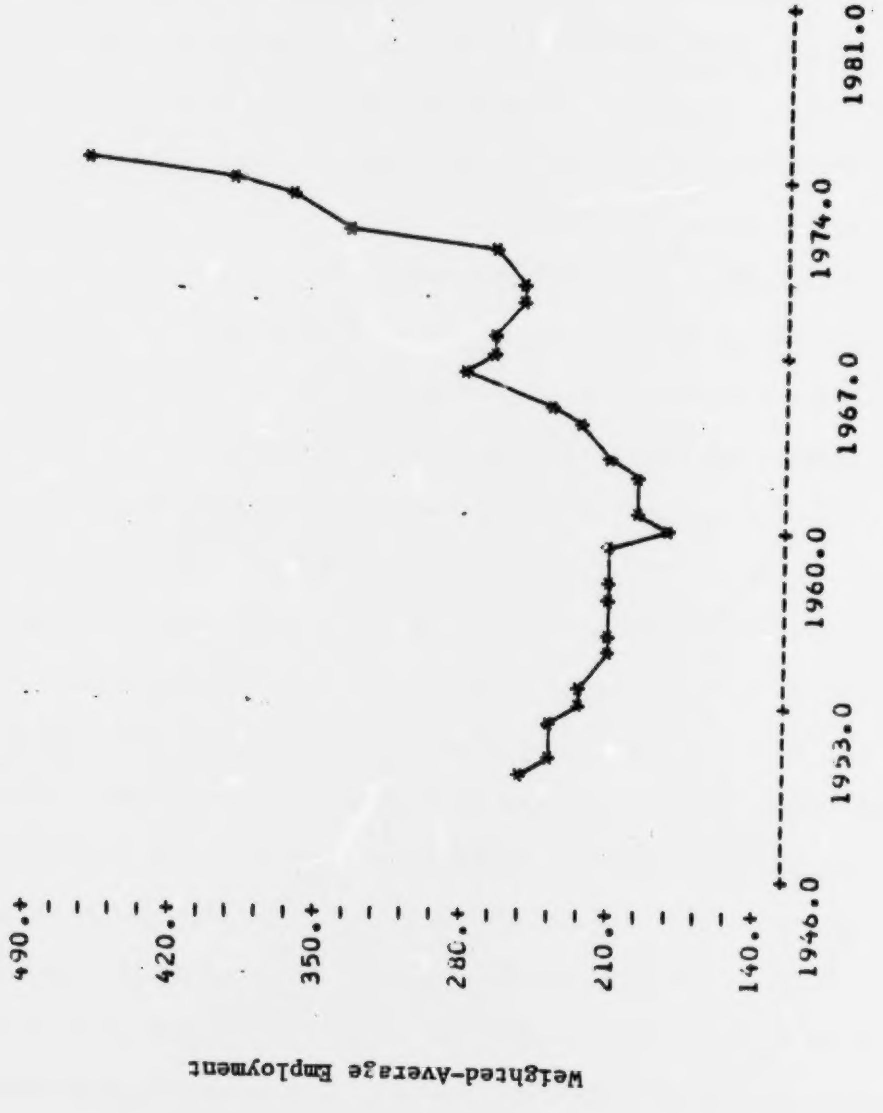


Figure 166. Trend of Weighted-Average Employment: Illinois (1950 Through 1975)

Results of Regressions for 1950 Through 1975

Results for appropriate regressions for the six injury rates are shown in Tables 97 and 98. The correlation matrices for the dependent variables are shown in Tables 99 and 100. The highest pairwise correlation is between AEMPL and MACT (0.90). Otherwise, the correlations are not high. Both FRMH and FRPR have autocorrelation, even using the Cochrane-Orcutt technique. Appropriate plots are presented in Figures 167 through 172. There is no evidence of heteroskedasticity in any of the residuals plots.

The regression of NFRMH (Equation 52) explains 90.0 percent of the variance, and all coefficients except that of ST are significant at the 99.0 percent confidence level or greater. All of the coefficients in the regression for NFRPR (Equation 53) are significant with the expected signs, and 95.0 percent of the variance is explained. Equation 55 for FRMH has significant coefficients for all variables except ST, and 80.0 percent of the variance is explained. For FRMHND (Equation 56), 54.0 percent of the variance is explained, and the coefficients for PMECH and MACT are significant with the expected signs. The equation for FRPR (Equation 58) explains 86.0 percent of the variance, but only the coefficient of PMECH is significant. Excluding disasters in the regression for FRPRND (Equation 59), all of the coefficients except that of AEMPL are significant and have the expected signs. Seventy-four percent of the variance is explained. The coefficients of ST are negative, as expected, in both cases for which they are significant--NFRPR and FRPRND. The coefficients of PMECH are negative and significant at the 97.5 percent confidence level or greater for all regressions.

Table 97

Results of Regressions for Injury Model: Illinois
(1950 Through 1975)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-Correlation (Durbin-Watson Statistic)	F-Statistic
52(OLS) NFRMH	1091.670 (95.189)	-4.028 (7.659)	-10.448 (0.945) #####	16.845 (3.762) ****		-0.318 (0.082) ####	0.90	3.43	None(2.11)	$45.76_{(4,21)}$
53(OLS) NFRPR	693.549 (35.929)	-10.505 (3.951) ####	-6.092 (0.437) #####		0.037 (0.014) ***	-0.200 (0.065) #####	0.95	1.86	None(1.49)	$104.17_{(4,21)}$
54(OLS) FRMH	81.347 (32.461)	0.947 (2.613)	-0.880 (0.322) ####	0.331 (1.283)		-0.007 (0.028)	0.40	1.17	-(3.43)	$3.43_{(4,21)}$
55(CORC) FRMH	131.951 (14.880)	0.259 (1.149)	-1.344 (0.147) #####	1.328 (0.544) **		-0.019 (0.012) #	0.80	0.68	+(1.33)	$20.40_{(4,20)}$
56(OLS) FRMHND	28.900 (8.710)	-0.925 (0.701)	-0.214 (0.086) ###	0.245 (0.344)		-0.015 (0.008) ##	0.54	0.31	None(2.20)	$6.10_{(4,21)}$
57(OLS) FRPR	49.618 (11.925)	0.314 (1.311)	-0.516 (0.145) #####		-0.000 (0.005)	-0.000 (0.0021)	0.49	0.62	-(2.93)	$4.95_{(4,21)}$

Table 97 (Continued)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-Correlation (Durbin-Watson Statistic)	F-Statistic
58(CORC) FRPR	65.721 (4.793)	0.353 (0.520)	-0.684 (0.061) #####		0.001 (0.002)	-0.003 (0.009)	0.86	0.33	+(1.24)	$29.52_{(4,20)}$
59(OLS) FRPRND	20.274 (2.956)	-0.839 (0.325) ####	-0.138 (0.036) #####		0.001 (0.001)	-0.010 (0.005) ##	0.74	0.15	None(2.07)	$15.22_{(4,21)}$

Significance Levels:
** Significant at the 95.0 percent confidence level (two-tail test)
*** Significant at the 98.0 percent confidence level (two-tail test)
**** Significant at the 99.0 percent confidence level (two-tail test)
# Significant at the 90.0 percent confidence level (one-tail test)
Significant at the 95.0 percent confidence level (one-tail test)
Significant at the 97.5 percent confidence level (one-tail test)
Significant at the 99.0 percent confidence level (one-tail test)
Significant at the 99.5 percent confidence level (one-tail test)

Table 98

Ninety-Five Percent Confidence Intervals for Coefficients in Illinois Regressions of Injury Model (1950 Through 1975)

Dependent Variable	ST		PMECH		AP		AEMPL		MACT	
52(OLS) NFRMH	-19.96	11.90	-12.41	-8.48	9.02	24.67			-0.49	-0.15
53(OLS) NFRPR	-18.72	-2.29	-7.00	-5.18			0.01	0.07	-0.33	-0.07
54(OLS) FRMH	-4.49	6.38	-1.55	-0.21	-2.34	0.33			-0.06	0.05
55(CORC) FRMH	-2.14	2.66	-1.65	-1.04	0.19	2.46			-0.04	0.01
56(OLS) FRMHND	-2.38	0.53	-0.39	-0.04	-0.47	0.96			-0.03	0.00
57(OLS) FRPR	-2.41	3.04	-0.82	-0.21			-0.01	0.01	-0.04	0.04
58(CORC) FRPR	-0.77	1.44	-0.81	-0.56			-0.00	0.00	-0.02	0.02
59(OLS) FRPRND	-1.51	-0.16	-0.21	-0.06			-0.00	0.00	-0.02	0.00

Table 99

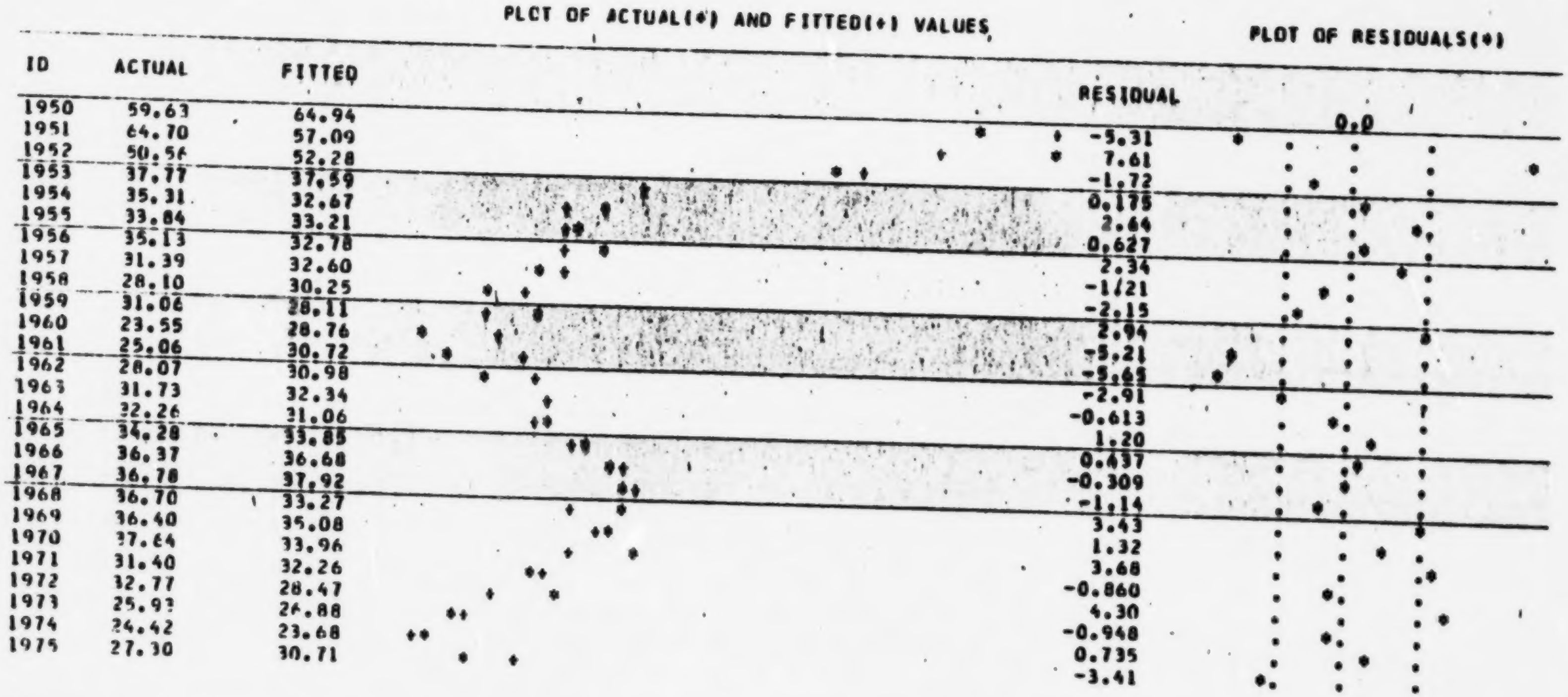
Pairwise Correlation Matrix for ST, PMECH, AP, and MACT: Illinois (1950 Through 1975)

	ST	PMECH	AP	MACT
ST	1.0005	0.39123	0.14081	-0.42803
PMECH	0.39123	1.0006	0.67745	0.24439
AP	0.14081	0.67745	1.0000	0.64919
MACT	-0.42803	0.24439	0.64919	1.0000

Table 100

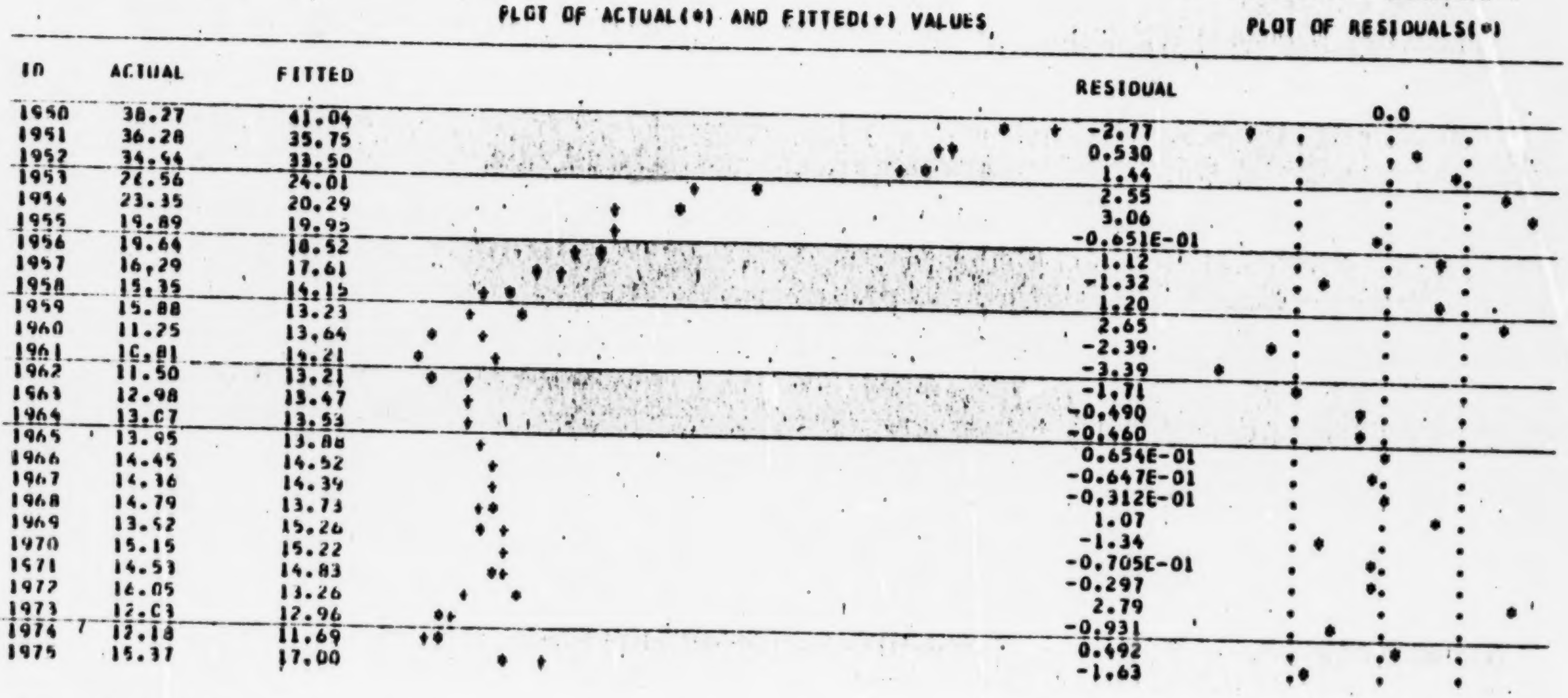
Pairwise Correlation Matrix for ST, PMECH, AEMPL, and MACT: Illinois (1950 Through 1975

	ST	PMECH	AEMPL	MACT
ST	1.0005	0.39123	-0.34712	-0.42803
PMECH	0.39123	1.0006	0.17253	0.24439
AEMPL	-0.34712	0.17253	1.0000	0.90180
MACT	-0.42803	0.24439	0.90180	1.0000



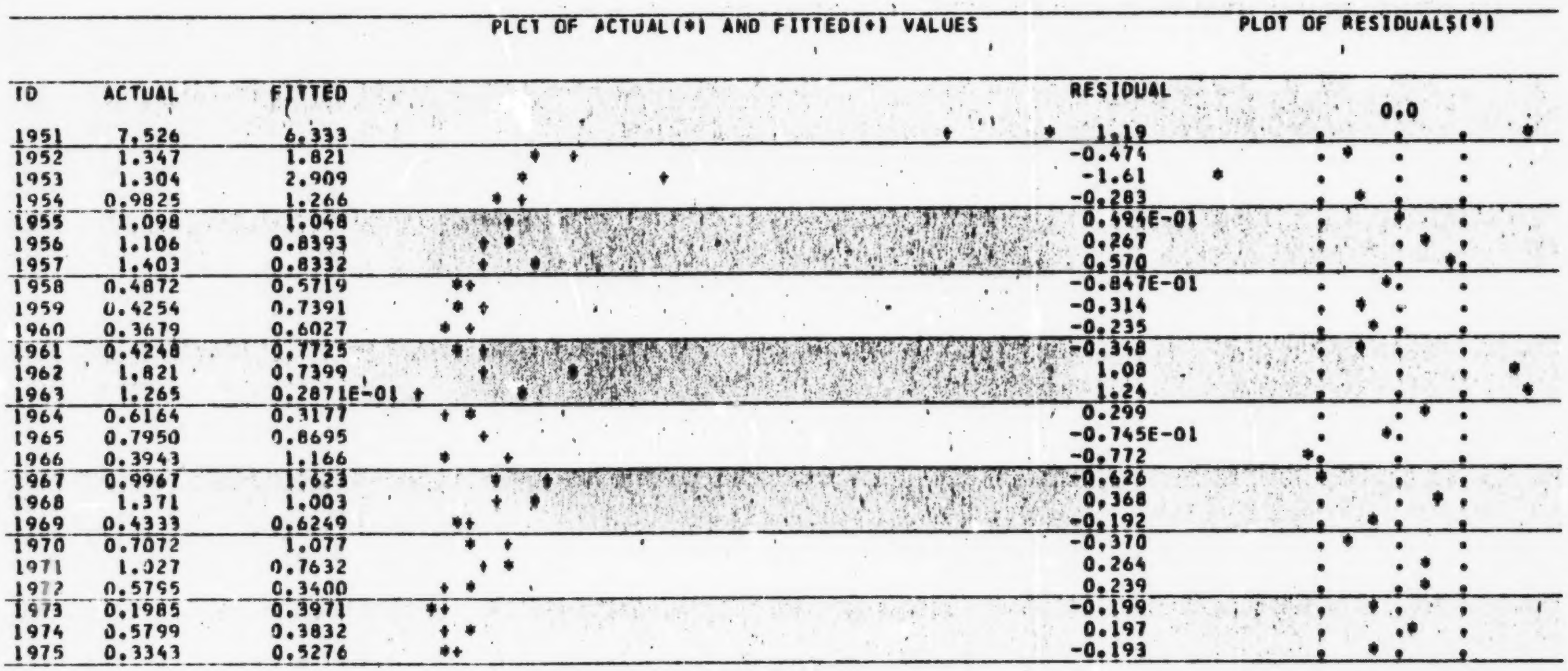
```
ID      ACTUAL     FITTED     RESIDUAL
1950    59.63      64.94      -5.31
1951    64.70      57.09       7.61
1952    50.56      52.28      -1.72
1953    37.77      37.59       0.175
1954    35.31      32.67       2.64
1955    33.84      33.21       0.627
1956    35.13      32.78       2.34
1957    31.39      32.60      -1.21
1958    28.10      30.25      -2.15
1959    31.06      28.11       2.94
1960    23.55      28.76      -5.21
1961    25.06      30.72      -5.65
1962    28.07      30.98      -2.91
1963    31.73      32.34      -0.613
1964    32.26      31.06       1.20
1965    34.28      33.85       0.437
1966    36.37      36.68      -0.309
1967    36.78      37.92      -1.14
1968    36.70      33.27       3.43
1969    36.40      35.08       1.32
1970    37.64      33.96       3.68
1971    31.40      32.26      -0.860
1972    32.77      28.47       4.30
1973    25.93      26.88      -0.948
1974    24.42      23.68       0.735
1975    27.30      30.71      -3.41
```

Figure 167. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1950 Through 1975: Illinois (OLS)



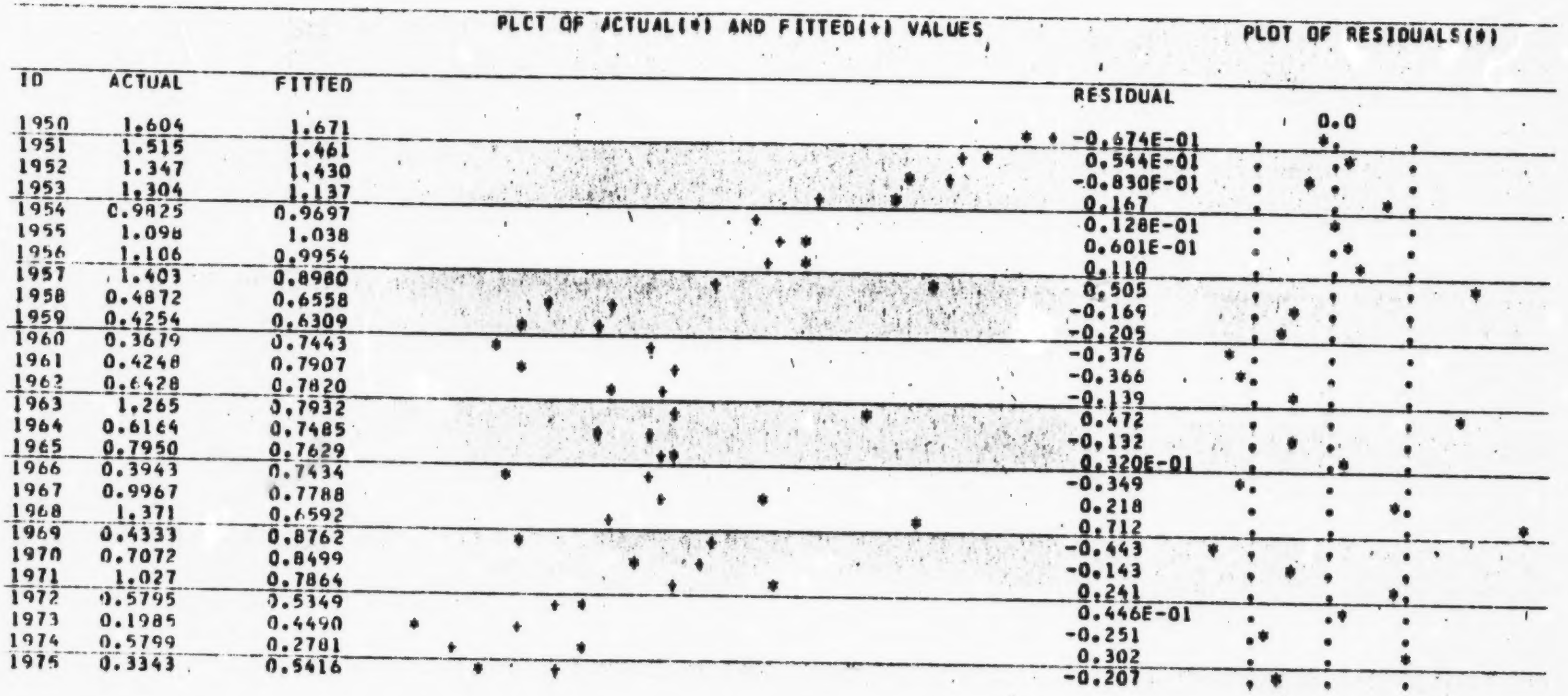
```
                PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID     ACTUAL     FITTED                              RESIDUAL
1950   38.27      41.04                                          0.0
1951   36.28      35.75                               -2.77
1952   34.44      33.50                                0.530
1953   26.56      24.01                                1.44
1954   23.35      20.29                                2.55
1955   19.89      19.95                                3.06
1956   19.64      18.52                               -0.651E-01
1957   16.29      17.61                                1.12
1958   15.35      14.15                               -1.32
1959   15.88      13.23                                1.20
1960   11.25      13.64                                2.65
1961   10.81      14.21                               -2.39
1962   11.50      13.21                               -3.39
1963   12.98      13.47                               -1.71
1964   13.07      13.53                               -0.490
1965   13.95      13.88                               -0.460
1966   14.45      14.52                                0.654E-01
1967   14.36      14.39                               -0.647E-01
1968   14.79      13.73                               -0.312E-01
1969   13.92      15.26                                1.07
1970   15.15      15.22                               -1.34
1971   14.53      14.83                               -0.705E-01
1972   16.05      13.26                               -0.297
1973   12.03      12.96                                2.79
1974   12.18      11.69                               -0.931
1975   15.37      17.00                                0.492
                                                      -1.63
```

Figure 168. Plots for Nonfatal Injury Rate Per Million Tons, 1950 Through 1975: Illinois (OLS)



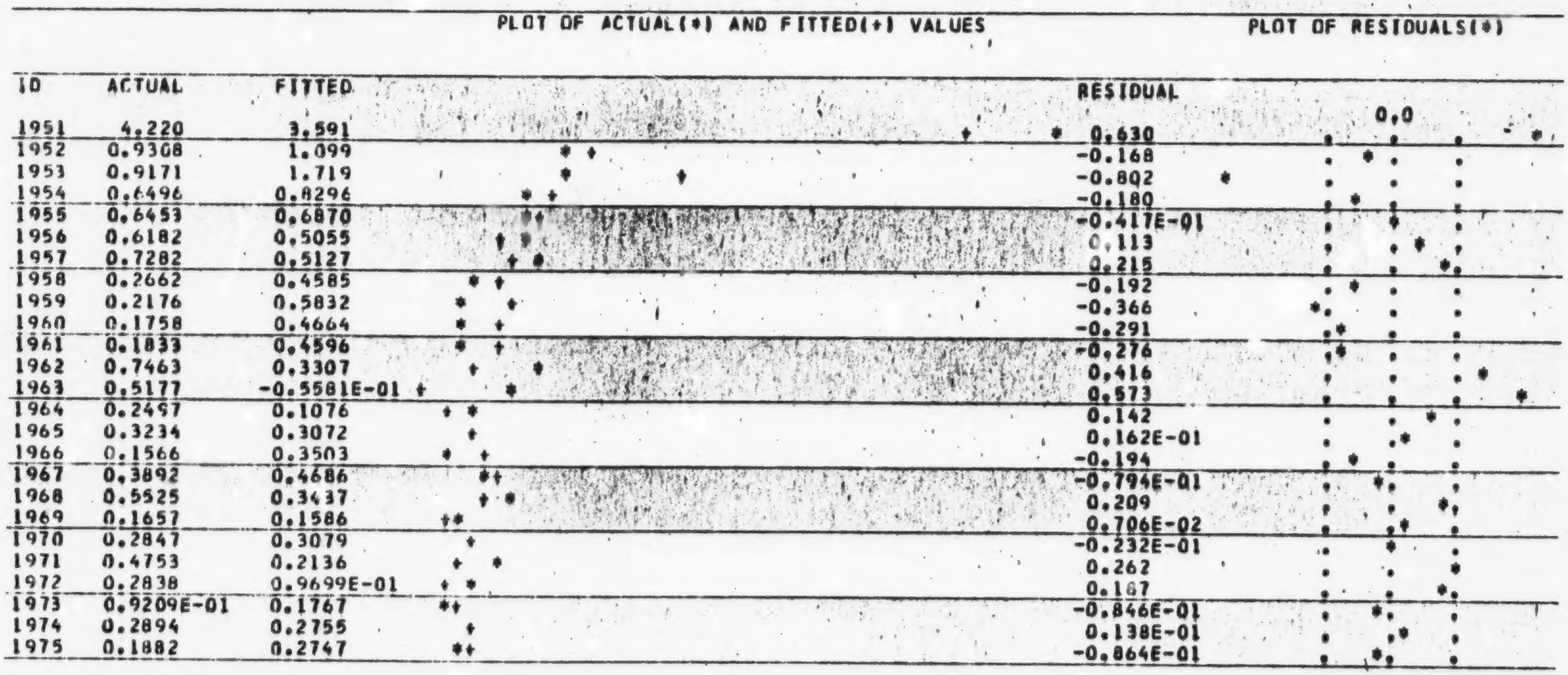
```
                                    PLCT OF ACTUAL(*) AND FITTED(+) VALUES            PLOT OF RESIDUALS(*)

ID     ACTUAL        FITTED                                              RESIDUAL
                                                                                          0.0
1951    7.526         6.333                                              1.19
1952    1.347         1.821                                             -0.474
1953    1.304         2.909                                             -1.61
1954   0.9825         1.266                                             -0.283
1955    1.098         1.048                                             0.494E-01
1956    1.106        0.8393                                             0.267
1957    1.403        0.8332                                             0.570
1958   0.4872        0.5719                                            -0.847E-01
1959   0.4254        0.7391                                            -0.314
1960   0.3679        0.6027                                            -0.235
1961   0.4248        0.7725                                            -0.348
1962    1.821        0.7399                                             1.08
1963    1.265        0.2871E-01                                         1.24
1964   0.6164        0.3177                                             0.299
1965   0.7950        0.8695                                            -0.745E-01
1966   0.3943         1.166                                            -0.772
1967   0.9967         1.623                                            -0.626
1968    1.371         1.003                                             0.368
1969   0.4333        0.6249                                            -0.192
1970   0.7072         1.077                                            -0.370
1971    1.027        0.7632                                             0.264
1972   0.5795        0.3400                                             0.239
1973   0.1985        0.3971                                            -0.199
1974   0.5799        0.3832                                             0.197
1975   0.3343        0.5276                                            -0.193
```

Figure 169. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1975: Illinois (CORC)



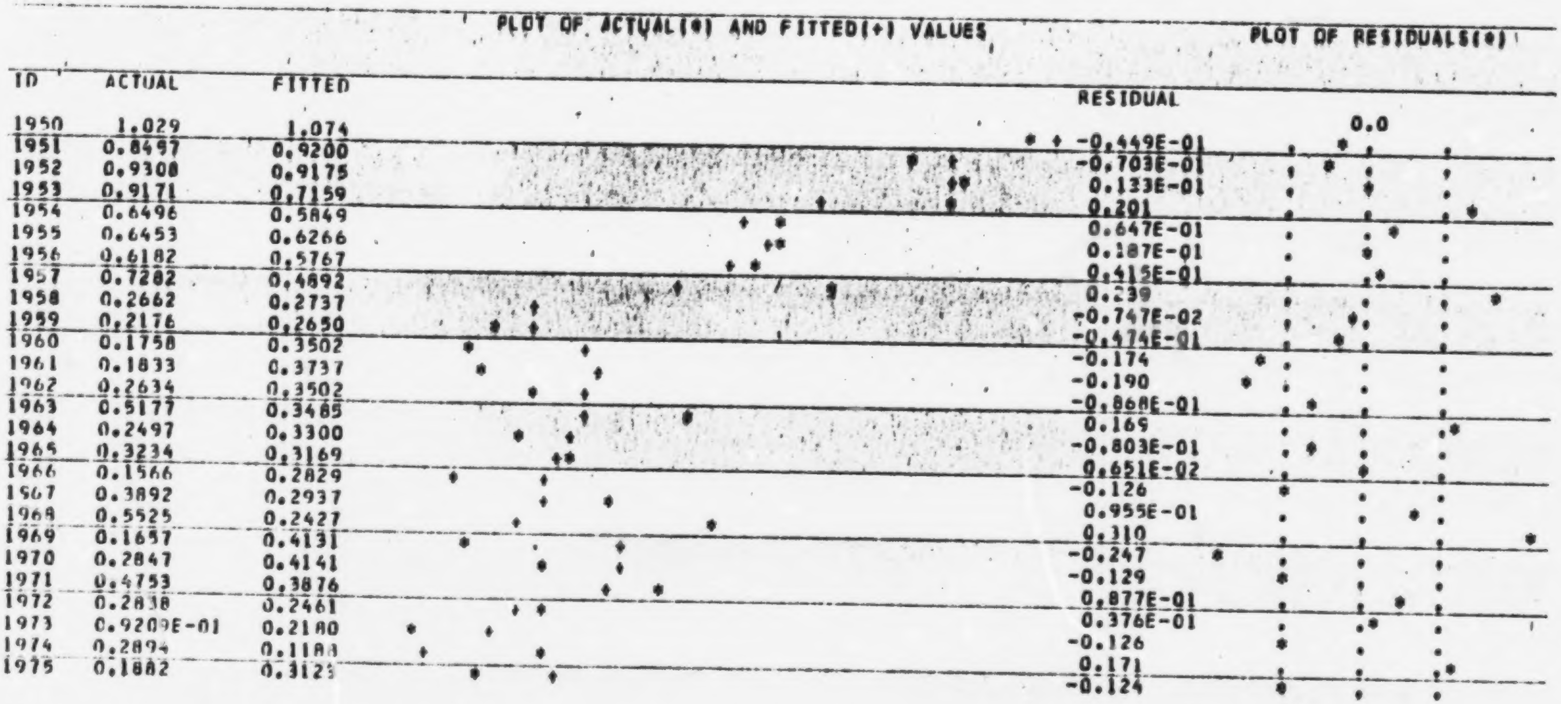
ID	ACTUAL	FITTED	RESIDUAL
1950	1.604	1.671	-0.674E-01
1951	1.515	1.461	0.544E-01
1952	1.347	1.430	-0.830E-01
1953	1.304	1.137	0.167
1954	0.9825	0.9697	0.128E-01
1955	1.098	1.038	0.601E-01
1956	1.106	0.9954	0.110
1957	1.403	0.8980	0.505
1958	0.4872	0.6558	-0.169
1959	0.4254	0.6309	-0.205
1960	0.3679	0.7443	-0.376
1961	0.4248	0.7907	-0.366
1962	0.6428	0.7820	-0.139
1963	1.265	0.7932	0.472
1964	0.6164	0.7485	-0.132
1965	0.7950	0.7629	0.320E-01
1966	0.3943	0.7434	-0.349
1967	0.9967	0.7788	0.218
1968	1.371	0.6592	0.712
1969	0.4333	0.8762	-0.443
1970	0.7072	0.8499	-0.143
1971	1.027	0.7864	0.241
1972	0.5795	0.5349	0.446E-01
1973	0.1985	0.4490	-0.251
1974	0.5799	0.2781	0.302
1975	0.3343	0.5416	-0.207

Figure 170. Plots for Fatal Injury Rate Excluding Disasters Per Million Man-Hours, 1950 Through 1975: Illinois (OLS)



```
                                      PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)

ID      ACTUAL        FITTED                                    RESIDUAL
                                                                                 0.0
1951     4.220         3.591                                     0.630
1952    0.9308         1.099                                    -0.168
1953    0.9171         1.719                                    -0.802
1954    0.6496        0.8296                                    -0.180
1955    0.6453        0.6870                                    -0.417E-01
1956    0.6182        0.5055                                     0.113
1957    0.7282        0.5127                                     0.215
1958    0.2662        0.4585                                    -0.192
1959    0.2176        0.5832                                    -0.366
1960    0.1758        0.4664                                    -0.291
1961    0.1833        0.4596                                    -0.276
1962    0.7463        0.3307                                     0.416
1963    0.5177       -0.5581E-01                                 0.573
1964    0.2497        0.1076                                     0.142
1965    0.3234        0.3072                                     0.162E-01
1966    0.1566        0.3503                                    -0.194
1967    0.3892        0.4686                                    -0.794E-01
1968    0.5525        0.3437                                     0.209
1969    0.1657        0.1586                                     0.706E-02
1970    0.2847        0.3079                                    -0.232E-01
1971    0.4753        0.2136                                     0.262
1972    0.2838        0.9699E-01                                 0.167
1973    0.9209E-01    0.1767                                    -0.846E-01
1974    0.2894        0.2755                                     0.138E-01
1975    0.1882        0.2747                                    -0.864E-01
```

Figure 171. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1975: Illinois (CORC)



```
PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID      ACTUAL         FITTED
                                    RESIDUAL
                                                           0.0
1950     1.029          1.074       -0.449E-01
1951    0.8497         0.9200       -0.703E-01
1952    0.9300         0.9175        0.133E-01
1953    0.9171         0.7159        0.201
1954    0.6496         0.5849        0.647E-01
1955    0.6453         0.6266        0.187E-01
1956    0.6182         0.5767        0.415E-01
1957    0.7282         0.4892        0.239
1958    0.2662         0.2737       -0.747E-02
1959    0.2176         0.2650       -0.474E-01
1960    0.1758         0.3502       -0.174
1961    0.1833         0.3737       -0.190
1962    0.2634         0.3502       -0.868E-01
1963    0.5177         0.3485        0.169
1964    0.2497         0.3300       -0.803E-01
1965    0.3234         0.3169        0.651E-02
1966    0.1566         0.2829       -0.126
1967    0.3892         0.2937        0.955E-01
1968    0.5525         0.2427        0.310
1969    0.1657         0.4131       -0.247
1970    0.2847         0.4141       -0.129
1971    0.4753         0.3876        0.877E-01
1972    0.2838         0.2461        0.376E-01
1973    0.9209E-01     0.2180       -0.126
1974    0.2894         0.1188        0.171
1975    0.1882         0.3123       -0.124
```

Figure 172. Plots for Fatal Injury Rate Excluding Disasters Per Million Tons, 1950 Through 1975: Illinois (OLS)

The coefficients of AP are significant and positive for NFRMH and FRMH; those of AEMPL are significant and positive only for NFRPR. All coefficients of MACT are negative; they are significant for all injury rates except FRPR.

Results of Regressions for 1950 Through 1969 and Predictions of Productivity

In this section, results of regressions on data through 1969 are presented, and predictions of injury rates are made assuming there is no CMHSA. The trends of the independent variables, as discussed, suggest that they are not affected by the Mine Act. In Tables 101 and 102, the results of regressions are given, and correlation matrices are presented in Tables 103 and 104. The degree of pairwise correlation is not high. The results for nonfatal injury rates are good, with 90.0 and 96.0 percent of the variance explained for NFRMH and NFRPR, respectively. Equations 64 and 67 for FRMH and FRPR explain 80.0 and 86.0 percent of the variance, but both have positive autocorrelation.[1] Equations 65 and 68 for FRMHND and FRPRND explain 49.0 and 77.0 percent of the variance, respectively. Appropriate plots are presented in Figures 173 through 178. There is no evidence for heteroskedasticity. The coefficients of ST are negative and significant in regressions for NFRPR and FRPRND. The coefficients of PMECH are negative and significant in all regressions. The coefficients of the mine-size variables are positive and significant for the nonfatal injury rates; the only fatal injury rate for which the coefficient is significant is FRMH.

The regression results were used to extrapolate possible injury rates in 1970 through 1975 in the absence of new federal legislation.

Table 101

Results of Regressions for Injury Model: Illinois
(1950 Through 1969)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	R^2	S	Auto-correlation (Durbin-Watson statistic)	F-Statistic
60(OLS) NFRMI	1101.86 (102.682)	-3.831 (8.804)	-10.568 (0.9[illegible]0) #####	16.916 (4.365) #####		0.90	3.54	None(2.10)	$50.07_{(3,16)}$
61(OLS) NFRPR	685.734 (37.815)	-12.881 (4.498) ####	-5.877 (0.495) #####		0.055 (0.020) ####	0.96	1.90	+(1.39)	$123.87_{(3,16)}$
62(CORC) NFRPR	777.218 (65.507)	-7.485 (4.445) #	-7.200 (0.749) #####		0.056 (0.022) ###	0.96	1.60	None(1.91)	$125.57_{(3,15)}$
63(OLS) FRMH	81.709 (38.703)	1.035 (3.318)	-0.890 (0.370) ###	0.314 (1.645)		0.36	1.33	-(2.87)	$3.05^{\ddagger}_{(3,16)}$
64(CORC) FRMI	133.363 (17.433)	0.111 (1.482)	-1.348 (0.166) #####	1.415 (0.698) *		0.80	0.77	+(1.28)	$20.02_{(3,15)}$
65(OLS) FRMHND	31.526 (9.666)	-1.172 (0.829)	-0.223 (0.092) ###	0.390 (0.411)		0.49	0.33	None(2.10)	$5.06_{(3,16)}$
66(OLS) FRPR	50.032 (14.018)	0.377 (1.667)	-0.525 (0.183) ####		0.000 (0.007)	0.46	0.70	-(2.93)	$4.52_{(3,16)}$

Table 101 (Continued)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	R^2	S	Auto-correlation (Durbin-Watson statistic)	F-Statistic
67(CORC) FRPR	66.326 (5.538)	0.464 (0.639)	-0.698 (0.075) #####		0.001 (0.003)	0.86	0.37	+(1.22)	$29.72_{(3,15)}$
68(OLS) FRPRND	19.241 (3.042)	-1.098 (0.362) #####	-0.112 (0.040) ####		0.002 (0.002)	0.77	0.15	None(2.02)	$17.59_{(3,16)}$

‡The equation is not significant at the 95.0 percent confidence level or greater.

Significance Levels:
* Significant at the 90.0 percent confidence level (two-tail test)
# Significant at the 90.0 percent confidence level (one-tail test)
### Significant at the 97.5 percent confidence level (one-tail test)
#### Significant at the 99.0 percent confidence level (one-tail test)
##### Significant at the 99.5 percent confidence level (one-tail test)

Table 102

Ninety-Five Percent Confidence Intervals for Coefficients in Illinois Regressions of Injury Model (1950 Through 1969)

Equation Dependent Variable	ST		PMECH		AP		AEMPL	
60(OLS) NFRMH	-22.50	14.83	-12.65	-8.49	7.66	26.17		
61(OLS) NFRPR	-22.42	-3.35	-6.93	-4.83			0.01	0.10
62(CORC) NFRPR	-16.96	1.99	-8.80	-5.60			0.009	0.103
63(OLS) FRMH	-6.00	8.07	-1.67	-0.11	-3.17	3.80		
64(CORC) FRMH	-3.05	3.27	-1.70	-0.99	-0.07	2.90		
65(OLS) FRMHND	-2.93	0.59	-0.42	-0.03	-0.48	1.26		
66(OLS) FRPR	-3.16	3.91	-0.91	-0.14			-0.02	0.01
67(CORC) FRPR	-0.90	1.83	-0.86	-0.54			-0.00	0.01
68(OLS) FRPRND	-1.87	-0.33	-0.20	-0.03			-0.00	0.01

Table 103

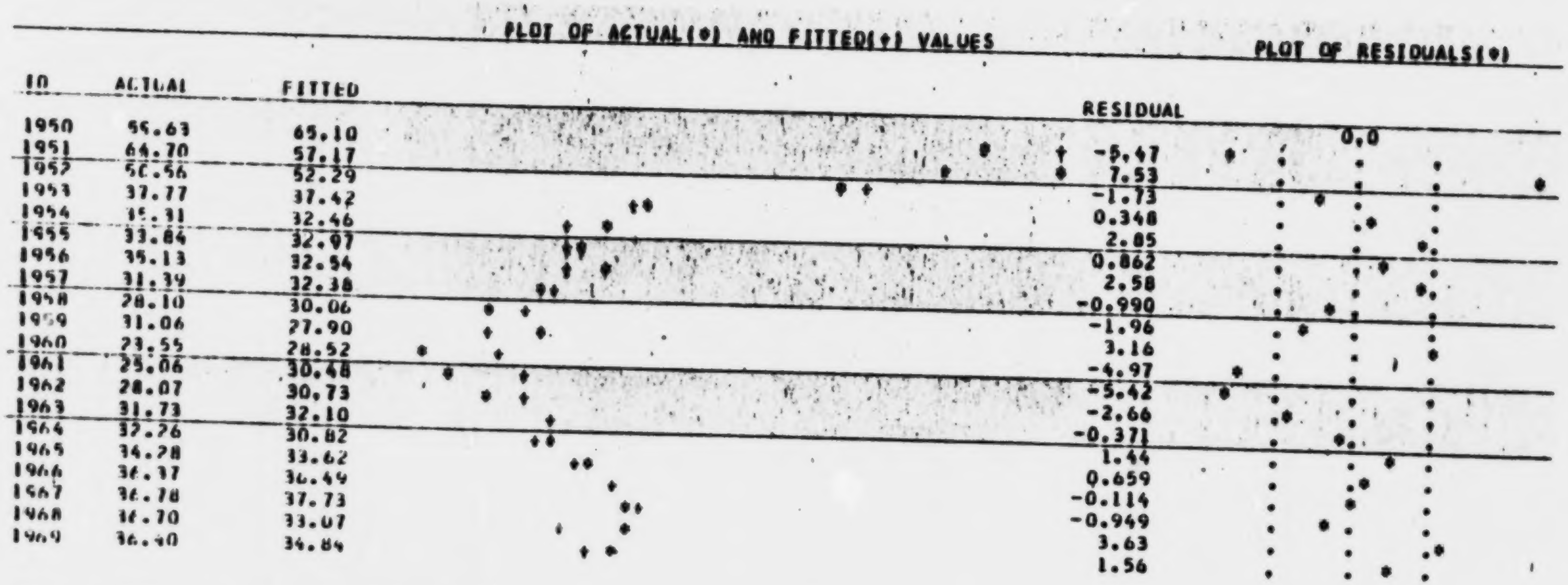
Pairwise Correlation Matrix for ST, PMECH, and AP: Illinois (1950 Through 1969)

	ST	PMECH	AP
ST	1.0004	0.60053	0.69814
PMECH	0.60053	1.0006	0.70308
AP	0.69814	0.70308	1.0000

Table 104

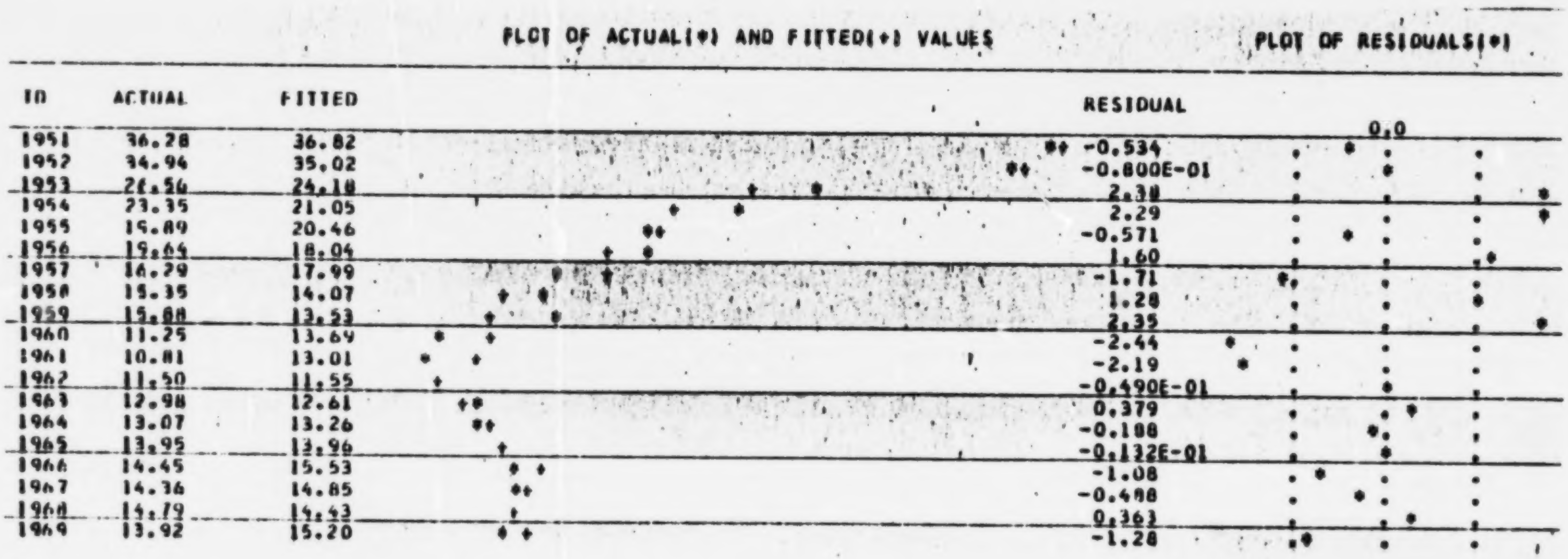
Pairwise Correlation Matrix for ST, PMECH, and AEMPL: Illinois (1950 Through 1969)

	ST	PMECH	AEMPL
ST	1.0004	0.60053	0.20533
PMECH	0.60053	1.0006	-0.17773
AEMPL	0.20533	-0.17773	1.0000



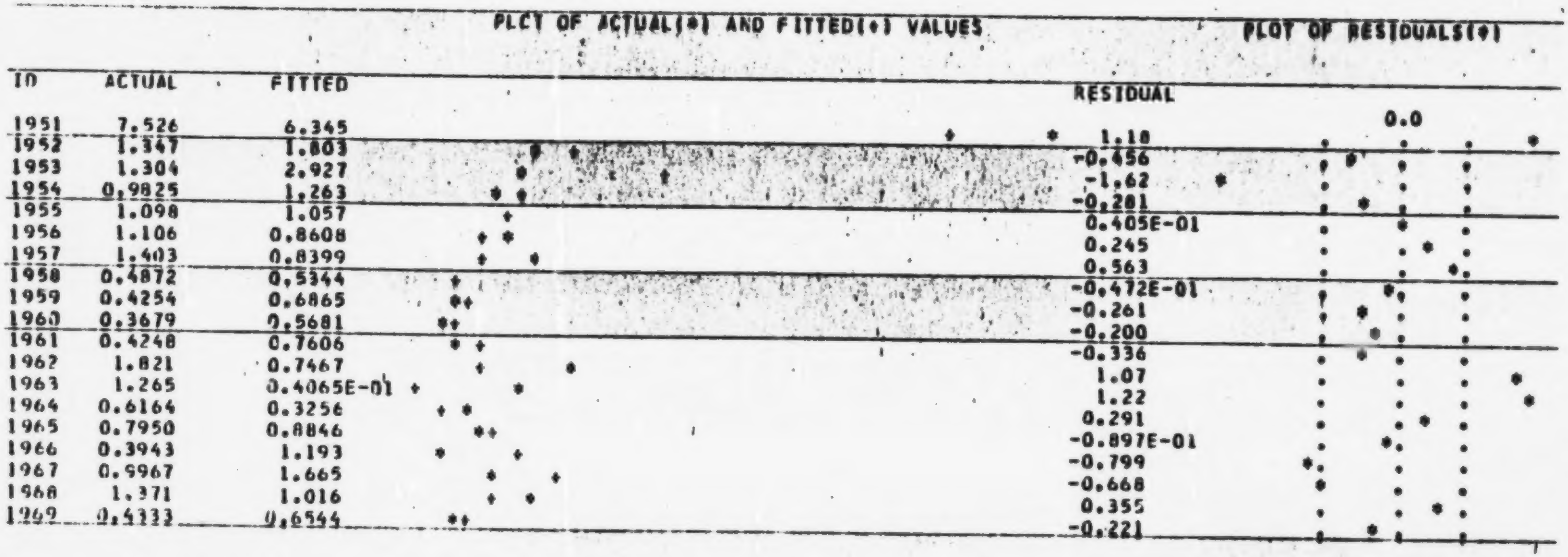
ID	ACTUAL	FITTED	RESIDUAL
1950	55.63	65.10	-9.47
1951	64.70	57.17	7.53
1952	50.56	52.29	-1.73
1953	37.77	37.42	0.348
1954	35.31	32.46	2.85
1955	33.84	32.97	0.862
1956	35.13	32.54	2.58
1957	31.39	32.38	-0.990
1958	28.10	30.06	-1.96
1959	31.06	27.90	3.16
1960	23.55	28.52	-4.97
1961	25.06	30.48	-5.42
1962	28.07	30.73	-2.66
1963	31.73	32.10	-0.371
1964	32.26	30.82	1.44
1965	34.28	33.62	0.659
1966	36.37	36.49	-0.114
1967	36.78	37.73	-0.949
1968	36.70	33.07	3.63
1969	36.40	34.84	1.56

Figure 173. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1950 Through 1969: Illinois (OLS)



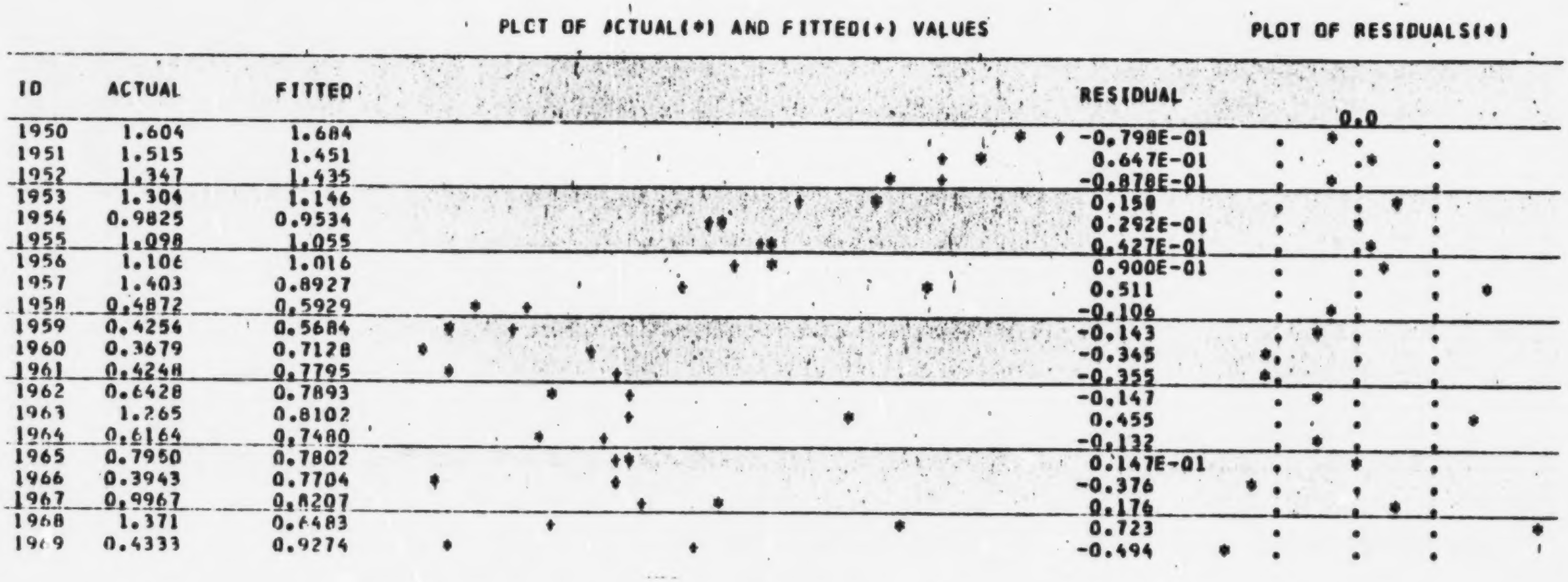
```
ID      ACTUAL      FITTED      RESIDUAL
1951    36.28       36.82       -0.534
1952    34.94       35.02       -0.800E-01
1953    26.56       24.18        2.38
1954    23.35       21.05        2.29
1955    19.89       20.46       -0.571
1956    19.64       18.04        1.60
1957    16.29       17.99       -1.71
1958    15.35       14.07        1.28
1959    15.88       13.53        2.35
1960    11.25       13.69       -2.44
1961    10.81       13.01       -2.19
1962    11.50       11.55       -0.490E-01
1963    12.98       12.61        0.379
1964    13.07       13.26       -0.188
1965    13.95       13.96       -0.132E-01
1966    14.45       15.53       -1.08
1967    14.36       14.85       -0.488
1968    14.79       14.43        0.363
1969    13.92       15.20       -1.28
```

Figure 174. Plots for Nonfatal Injury Rate Per Million Tons, 1950 Through 1969: Illinois (CORC)



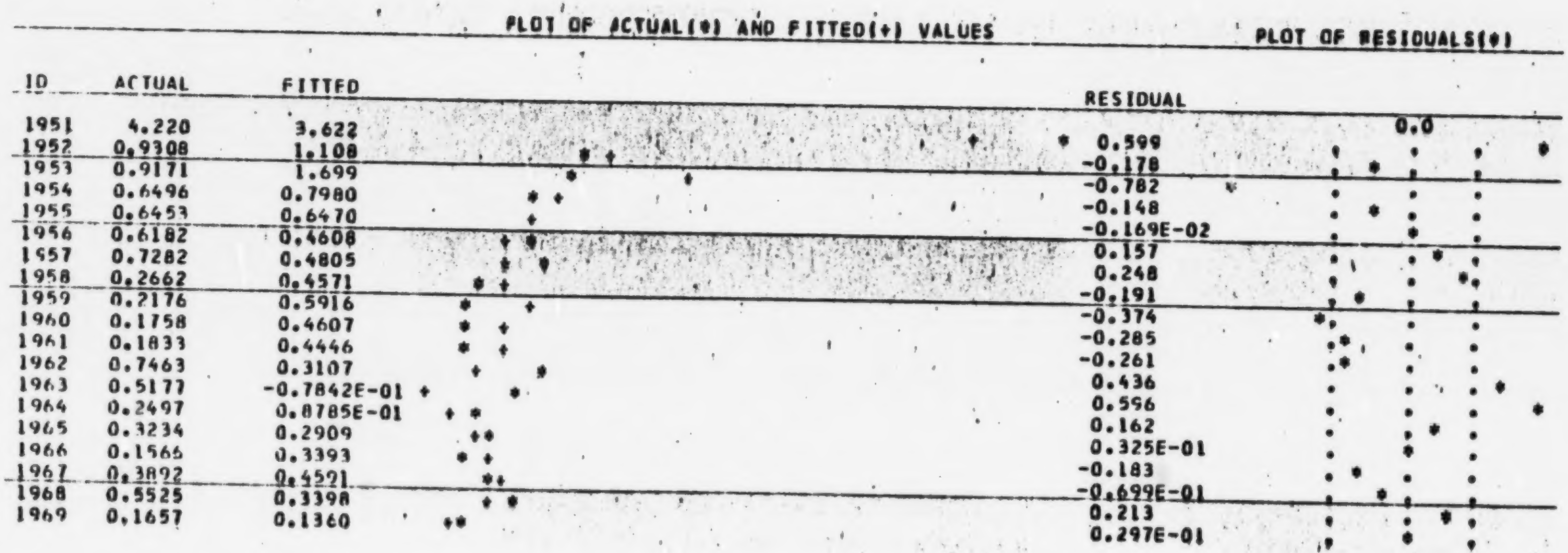
```
                                  PLCT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)
ID      ACTUAL       FITTED                                              RESIDUAL
                                                                                         0.0
1951     7.526        6.345                                                1.18
1952     1.347        1.803                                               -0.456
1953     1.304        2.927                                               -1.62
1954    0.9825        1.263                                               -0.281
1955     1.098        1.057                                               0.405E-01
1956     1.106       0.8608                                                0.245
1957     1.403       0.8399                                                0.563
1958    0.4872       0.5344                                              -0.472E-01
1959    0.4254       0.6865                                               -0.261
1960    0.3679       0.5681                                               -0.200
1961    0.4248       0.7606                                               -0.336
1962     1.821       0.7467                                                1.07
1963     1.265       0.4065E-01                                            1.22
1964    0.6164       0.3256                                                0.291
1965    0.7950       0.8846                                              -0.897E-01
1966    0.3943        1.193                                               -0.799
1967    0.9967        1.665                                               -0.668
1968     1.371        1.016                                                0.355
1969    0.4333       0.6544                                               -0.221
```

Figure 175. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1969: Illinois (CORC)



ID	ACTUAL	FITTED	RESIDUAL
1950	1.604	1.684	-0.798E-01
1951	1.515	1.451	0.647E-01
1952	1.347	1.435	-0.878E-01
1953	1.304	1.146	0.158
1954	0.9825	0.9534	0.292E-01
1955	1.098	1.055	0.427E-01
1956	1.106	1.016	0.900E-01
1957	1.403	0.8927	0.511
1958	0.4872	0.5929	-0.106
1959	0.4254	0.5684	-0.143
1960	0.3679	0.7128	-0.345
1961	0.4248	0.7795	-0.355
1962	0.6428	0.7893	-0.147
1963	1.265	0.8102	0.455
1964	0.6164	0.7480	-0.132
1965	0.7950	0.7802	0.147E-01
1966	0.3943	0.7704	-0.376
1967	0.9967	0.8207	0.176
1968	1.371	0.6483	0.723
1969	0.4333	0.9274	-0.494

Figure 176. Plots for Fatal Injury Rate Excluding Disasters Per Million Man-Hours, 1950 Through 1969: Illinois (OLS)



```
                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(*)
ID     ACTUAL       FITTED
                                                                        RESIDUAL
                                                                                            0.0
1951   4.220        3.622                                                0.599
1952   0.9308       1.108                                               -0.178
1953   0.9171       1.699                                               -0.782
1954   0.6496       0.7980                                              -0.148
1955   0.6453       0.6470                                              -0.169E-02
1956   0.6182       0.4608                                               0.157
1957   0.7282       0.4805                                               0.248
1958   0.2662       0.4571                                              -0.191
1959   0.2176       0.5916                                              -0.374
1960   0.1758       0.4607                                              -0.285
1961   0.1833       0.4446                                              -0.261
1962   0.7463       0.3107                                               0.436
1963   0.5177      -0.7842E-01                                           0.596
1964   0.2497       0.8785E-01                                           0.162
1965   0.3234       0.2909                                               0.325E-01
1966   0.1566       0.3393                                              -0.183
1967   0.3892       0.4521                                              -0.699E-01
1968   0.5525       0.3398                                               0.213
1969   0.1657       0.1360                                               0.297E-01
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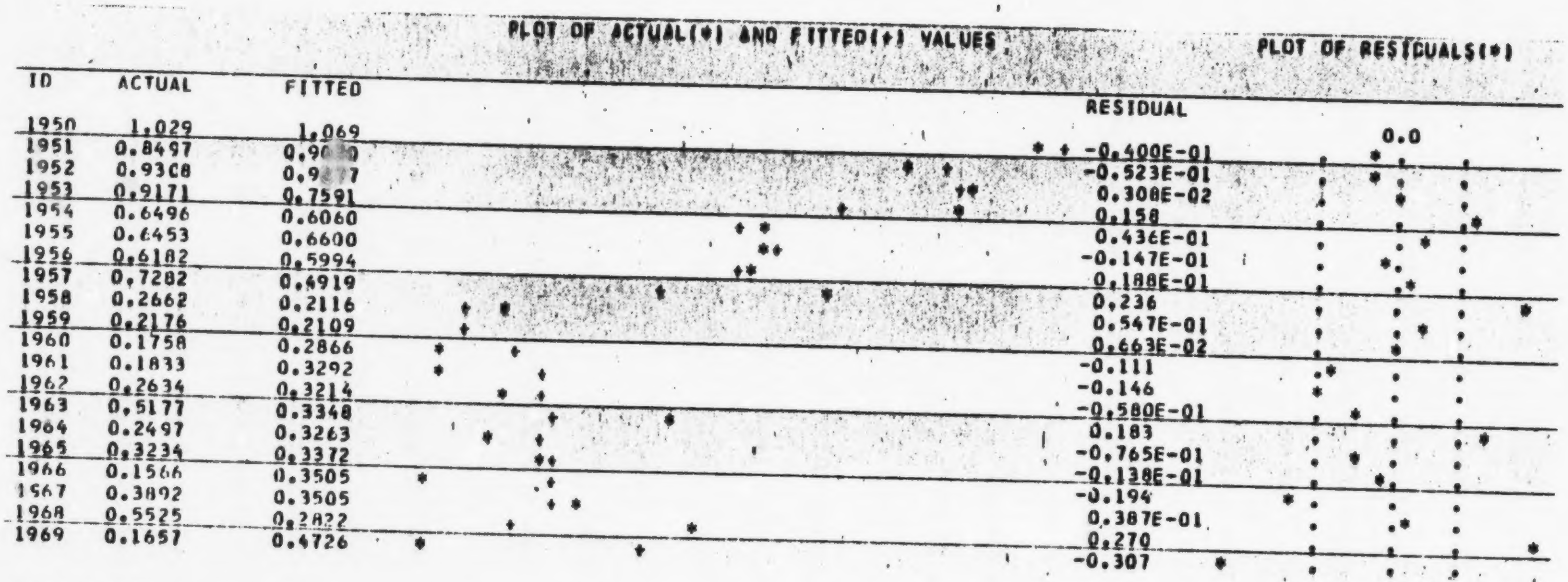
Figure 177. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1969: Illinois (CORC)



```
                                 PLOT OF ACTUAL(*) AND FITTED(+) VALUES            PLOT OF RESIDUALS(*)
 ID     ACTUAL       FITTED
                                                             RESIDUAL
 1950    1.029        1.069                                                             0.0
 1951   0.8497       0.90[illegible]                         -0.400E-01
 1952   0.9308       0.9[illegible]77                        -0.523E-01
 1953   0.9171       0.7591                                   0.308E-02
 1954   0.6496       0.6060                                   0.158
 1955   0.6453       0.6600                                   0.436E-01
 1956   0.6182       0.5994                                  -0.147E-01
 1957   0.7282       0.4919                                   0.188E-01
 1958   0.2662       0.2116                                   0.236
 1959   0.2176       0.2109                                   0.547E-01
 1960   0.1758       0.2866                                   0.663E-02
 1961   0.1833       0.3292                                  -0.111
 1962   0.2634       0.3214                                  -0.146
 1963   0.5177       0.3348                                  -0.580E-01
 1964   0.2497       0.3263                                   0.183
 1965   0.3234       0.3372                                  -0.765E-01
 1966   0.1566       0.3505                                  -0.138E-01
 1967   0.3892       0.3505                                  -0.194
 1968   0.5525       0.2822                                   0.387E-01
 1969   0.1657       0.4726                                   0.270
                                                             -0.307
```

Figure 178. Plots for Fatal Injury Rate Excluding Disasters Per Million Tons, 1950 Through 1969: Illinois (OLS)

[illegible] are reported in Table 105. With a few exceptions, actual injury [illegible] are lower than predicted rates without the legislation. Almost [illegible] of the exceptions occur in 1970 and 1971. For nonfatal injury rates, actual values are significantly lower than predicted rates in 1973 through 1975. For all fatal injury rates, the only cases for which actual values are significantly less than predicted rates are for FRPRND in 1973 and 1975.

The results of the model using data through 1975 were used to make predictions of injury rates without the Mine Act. These predictions are shown in Tables 106 and 107. For NFRMH, actual rates are less than predicted rates in 1971 through 1975 and greater in 1970. Actual NFRPR are significantly less than predicted values in all years except 1972, for which the actual value is lower than the mean predicted value but within the prediction interval. For FRMH, actual values fall within prediction intervals in all years except 1970, in which the actual rate is less than predicted. For FRMHND actual values are significantly less than predicted in 1970, 1973, and 1975, but they fall within prediction intervals otherwise. For FRPR actual values fall within prediction intervals in all years except 1971, when the actual value exceeds the predicted rate. Excluding disaster fatalities (FRPRND), the results indicate that only in 1970 is the actual value less than predicted; otherwise, actual values fall within the prediction intervals. Tables 106 and 107 also show the percentage decreases in injury rates based on predictions by the model as compared to the predicted rates after eliminating the effects of MACT. For example, in 1975, actual NFRMH is lower than the predicted rate without MACT by 28.8 percent.

Table 10[illegible]

Comparison of Predicted Levels of Injury [illegible]gressions With Actual Injury Ra[illegible]

Injury Rate		1970	1971	[illegible]	[illegible]	1974	1975
NFRMH(OLS)	Predicted	35.35 (±8.66)	35.33 (±8.81)	37.[illegible] (±9.[illegible])	[illegible]	39.98 (±10.61)	42.90 (±11.94)
	Actual	37.64	31.40	32.[illegible]	[illegible]	24.42	27.30
NFRPR(CORC)	Predicted	16.31 (±4.11)	17.17 (±4.49)	20.48 (±6.20)	[illegible] ([illegible].03)	24.51 (±8.79)	28.38 (±11.43)
	Actual	15.15	14.53	16.05	12.03	12.18	15.37
FRMH(CORC)	Predicted	0.95 (±2.32)	0.94 (±2.40)	0.53 (±2.67)	1.31 (±3.44)	1.30 (±3.27)	1.54 (±3.88)
	Actual	0.71	1.03	0.58	0.20	0.58	0.33
FRMHND(OLS)	Predicted	0.99 (±0.81)	1.01 (±0.83)	1.06 (±0.88)	1.22 (±1.03)	1.19 (±1.00)	1.29 (±1.12)
	Actual	0.71	1.03	0.58	0.20	0.58	0.33
FRPR(CORC)	Predicted	0.24 (±1.01)	0.24 (±1.34)	0.30 (±2.07)	0.30 (±2.80)	0.38 (±3.11)	0.40 (±4.12)
	Actual	0.28	0.48	0.28	0.09	0.29	0.19
FRPRND(OLS)	Predicted	0.55 (±0.37)	0.61 (±0.40)	0.75 (±0.52)	0.95 (±0.67)	0.98 (±0.73)	1.17 (±0.93)
	Actual	0.28	0.48	0.28	0.09	0.29	0.19

‡Prediction intervals for a 95.0 percent confidence level are given in parentheses.

Table 106

Effect of MACT on Nonfatal Injury Rates: Illinois

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT Mean			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
						Low	Mean	High		Low	Mean	High		
						Nonfatal Injuries Per Million Man-Hours								
NFRMH	1969	-0.488	-0.318	-0.147	0				35.08				36.40	
	1970				5.15924	0.76	1.64	2.52	33.96	34.72	35.60	36.48	37.64	4.6
	1971				10.4678	1.54	3.33	5.11	32.26	33.80	35.59	37.37	31.40	9.4
	1972				29.2330	4.30	9.30	14.27	28.47	32.77	37.77	42.74	32.77	24.6
	1973				42.6833	6.27	13.57	20.83	26.88	33.15	40.45	47.71	25.93	33.5
	1974				52.0947	7.66	16.57	25.42	23.68	31.34	40.25	49.10	24.42	42.0
	1975				39.1479	5.75	12.45	19.10	30.71	36.46	43.16	49.81	27.30	28.8
						Nonfatal Injuries Per Million Tons								
NFRPR	1969	-0.334	-0.200	-0.066	0				15.26				13.92	
	1970				5.15924	0.34	1.03	1.72	15.22	15.56	16.25	16.94	15.15	6.3
	1971				10.4678	0.69	2.09	3.50	14.83	15.52	16.92	18.33	14.53	12.4
	1972				29.2330	1.93	5.85	9.76	13.26	15.19	19.11	23.02	16.05	30.6
	1973				42.6833	2.82	8.54	14.26	12.96	15.78	21.50	27.22	12.03	39.7
	1974				52.0947	3.44	10.42	17.40	11.69	15.13	22.11	29.09	12.18	47.1
	1975				39.1479	2.58	7.83	13.08	17.00	19.58	24.83	30.08	15.37	31.5

Table 107

Effect of MACT on Fatal Injury Rates: Illinois

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT Mean			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean
						Low	Mean	High		Low	Mean	High		
						-((1) x (2))				(3) + (4)				(5) - (4)/(5)
						Fatal Injuries Per Million Man-Hours								
FRMH	1969	-0.044	-0.019	0.006	0				0.62				0.43	
	1970				5.15924	-0.03	0.10	0.23	1.08	1.05	1.18	1.31	0.71	8.5
	1971				10.4678	-0.06	0.20	0.46	0.76	0.70	0.96	1.22	1.03	20.8
	1972				29.2330	-0.18	0.56	1.29	0.34	0.16	0.90	1.63	0.58	62.2
	1973				42.6833	-0.26	0.81	1.88	0.40	0.14	1.21	2.28	0.20	66.9
	1974				52.0947	-0.31	0.99	2.29	0.38	0.07	1.37	2.67	0.58	72.3
	1975				39.1479	-0.23	0.74	1.72	0.53	0.30	1.27	2.25	0.33	58.3
						Fatal Injuries Excluding Disasters Per Million Man-Hours								
FRMHIND	1969	-0.031	-0.015	0.001	0				0.88				0.43	
	1970				5.15924	-0.01	0.08	.16	0.85	0.84	0.93	1.01	0.71	8.6
	1971				10.4678	-0.01	0.16	.33	0.79	0.78	0.95	1.12	1.03	16.8
	1972				29.2330	-0.03	0.44	.91	0.53	0.50	0.97	1.44	0.58	45.4
	1973				42.6833	-0.04	0.64	1.32	0.45	0.41	1.09	1.77	0.20	58.7
	1974				52.0947	-0.05	0.78	1.62	0.28	0.23	1.06	1.90	0.58	79.6
	1975				39.1479	-0.04	0.59	1.21	0.54	0.50	1.13	1.75	0.33	52.2
						Fatal Injuries Per Million Tons								
FRPR	1969	-0.022	-0.003	0.015	0				0.16				0.17	
	1970				5.15924	-0.09	0.02	0.11	0.31	0.23	0.33	0.42	0.28	6.1
	1971				10.4678	-0.16	0.03	0.23	0.21	0.05	0.24	0.44	0.48	12.5
	1972				29.2330	-0.44	0.09	0.64	0.10	<0	0.19	0.74	0.28	47.4
	1973				42.6833	-0.64	0.13	0.94	0.18	<0	0.31	1.12	0.09	41.9
	1974				52.0947	-0.78	0.16	1.15	0.28	<0	0.41	1.43	0.29	31.7
	1975				39.1479	-0.59	0.12	0.86	0.27	<0	0.39	1.13	0.19	30.8

Table 107 (Continued)

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT Mean			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
						Low	Mean	High		Low	Mean	High		
						Fatal Injuries Excluding Disasters Per Million Tons								
FRPRND	1969	-0.021	-0.010	0.001	0				0.41				0.17	
	1970				5.15924	0	0.05	0.10	0.41	0.41	0.46	0.51	0.28	10.9
	1971				10.4678	0	0.10	0.21	0.39	0.39	0.49	0.60	0.48	20.4
	1972				29.2330	0	0.29	0.58	0.25	0.25	0.54	0.83	0.28	53.7
	1973				42.6833	0	0.43	0.85	0.22	0.22	0.65	1.07	0.09	66.2
	1974				52.0947	0	0.52	1.04	0.12	0.12	0.64	1.16	0.29	81.3
	1975				39.1479	0	0.39	0.78	0.31	0.31	0.70	1.09	0.19	55.7

The corresponding comparisons for the other injury rates are: actual NFRPR is reduced by 31.5 percent, actual FRMH is reduced by 58.3 percent, actual FRMHND is reduced by 52.2 percent, actual FRPR is reduced by 30.8 percent, and actual FRPRND is higher in 1975 than predicted without MACT.

Summary

The relationships of the independent variables to the injury rates may be summarized as follows. For NFRMH: (1) weighted-average seam thickness is negatively related but not significant; (2) percent mechanically loaded is negatively related and significant; (3) average production is positively related and significant; and (4) the Mine-Act variable is negatively related and significant. For NFRPR: (1) weighted-average seam thickness is negatively related and significant; (2) percent mechanically loaded is negatively related and significant; (3) weighted-average employment is positively related and significant; and (4) the Mine-Act variable is negatively related and significant. For FRMH: (1) weighted-average seam thickness is positively related and not significant; (2) percent mechanically loaded is negatively related and significant; (3) average production is positively related and significant; and (4) the Mine-Act variable is negatively related and significant. For FRMHND: (1) weighted-average seam thickness is negatively related but not significant; (2) percent mechanically loaded is negatively related and significant; (3) average production is positively related and not significant; and (4) the Mine-Act variable is negatively related and significant. For FRPR: (1) weighted-average seam thickness is positively related and not significant; (2) percent mechanically loaded is negatively related and significant; (3) weighted-average employment is positively related and not significant; and (4) the Mine-Act variable is negatively related but not significant. For FRPRND: (1) weighted-average seam thickness is negatively related and significant; (2) percent mechanically loaded is negatively related and significant; (3) weighted-average employment is positively related and not significant; and (4) the Mine-Act variable is negatively related and significant.

The effects of each independent variable on the injury rates may be summarized as follows: (1) an increase in ST of one inch decreases NFRMH by 4.03, decreases NFRPR by 10.51, increases FRMH by 0.26, decreases FRMHND by 0.93, increases FRPR by 0.35, and decreases FRPRND by 0.84; (2) an increase in PMECH of one percent decreases NFRMH by 10.45, decreases NFRPR by 6.09, decreases FRMH by 1.34, decreases FRMHND by 0.21, decreases FRPR by 0.68, and decreases FRPRND by 0.14; (3) an increase in AP by one million tons increases NFRMH by 16.85, increases FRMH by 1.33, and increases FRMHND by 0.25; (4) an increase in AEMPL by ten increases NFRPR by 0.37, increases FRPR by 0.01, and increases FRPRND by 0.01; and (5) an increase in the value of MACT by one decreases NFRMH by 0.32, decreases NFRPR by 0.20, decreases FRMH by 0.02, decreases FRMHND by 0.02, decreases FRPR by 0.004, and decreases FRPRND by 0.01.

The results for the Mine-Act variable suggest that nonfatal injury rates may have been lowered, but the effect on fatal injury rates is less conclusive.

Ohio

Data and Trends of Variables

The data used for Ohio are presented in Table 108. The state data on total production and average production, man-days worked, and weighted-average employment were obtained from the Ohio Division of Mines Report for 1950 through 1975. Seam thickness data sources were discussed in the Ohio section of Chapter III. Data on injuries at the mine level were not available in state reports; therefore, they were estimated from other sources. The number of fatal injuries were obtained from the U.S. Bureau of Mines Minerals Yearbook for 1950 through 1975. Nonfatal injuries were derived using injury rates from Injury Experience in Coal Mining (U.S. Department of the Interior and U.S. Department of Labor) for 1950 through 1975 applied to man-hour and production totals per year from Table 25. Nonfatal injury rates per million tons multiplied by millions of tons and nonfatal injury rates per million man-hours multiplied by millions of man-hours give two estimates of the number of nonfatal injuries for a year. The average of these was used as an estimate of nonfatal injuries. Other data sources are as given in the section on methods of investigation.

The trends over time of the accident rates are shown in Figures 179 through 182. Nonfatal injury rates per million man-hours (NFRMH) show a generally declining trend from 1950 through 1963, then a steeply increasing trend through 1969, a more slowly increasing to level trend through 1972, and a declining trend thereafter (Figure 179). Piecewise regression results (Table 109) show these three breaks in trend in 1963, 1969, and 1972 to be significant at confidence levels of 99.0, 95.0, and

Table 108

Data for Ohio Injury Model

Year	Number of Nonfatal Injuries NFTL	Nonfatal Injury Rate Per Million Man-Hours NFRMH	Nonfatal Injury Rate Per Million Tons NFRPR	Total Number of Fatal Injuries FTL	Number of Disaster Fatalities DFTL	Fatal Injury Rate Per Million Man-Hours FRMH	Fatal Injury Rate Per Million Tons FRPR
1950	765	45.8255	53.8566	15	0	0.898538	1.05601
1951	721	39.6943	46.1583	22	0	1.21120	1.40844
1952	625	44.3381	46.9364	9	0	0.638469	0.675884
1953	571	44.9635	45.0619	12	0	0.944942	0.947010
1954	371	41.5852	38.3059	5	0	0.560448	0.516253
1955	470	43.1846	35.2251	11	0	1.01070	0.824417
1956	358	37.0208	29.4701	6	0	0.620461	0.493912
1957	271	34.5163	26.0179	4	0	0.509466	0.384029
1958	179	29.1863	21.5354	4	0	0.652209	0.481238
1959	228	36.0099	24.8734	1	0	0.157938	0.109094
1960	199	33.0324	22.6611	2	0	0.331984	0.227749
1961	191	36.4224	22.6431	5	0	0.953466	0.592753
1962	167	32.2143	18.5588	3	0	0.578700	0.333393
1963	144	26.6911	14.3855	3	0	0.556064	0.299697
1964	170	30.8446	16.6663	5	0	0.907195	0.490185
1965	217	39.7992	19.3540	4	0	0.733626	0.356756
1966	261	44.8610	20.0156	6	0	1.03129	0.460129
1967	295	46.6295	19.5123	3	0	0.474199	0.198431
1968	307	49.7710	18.8180	7	0	1.13484	0.429076
1969	434	59.7546	23.3827	8	0	1.10147	0.431017
1970	470	57.6626	24.8702	4	0	0.490745	0.211662
1971	499	59.5967	39.3129	2	0	0.238865	0.157567
1972	637	60.9944	39.1198	2	0	0.191505	0.122825
1973	553	50.7056	34.2094	2	0	0.183384	0.123723
1974	321	27.9191	22.2943	3	0	0.260927	0.208358
1975	449	31.9293	31.5289	4	0	0.284448	0.280881

Table 108 (Continued)

Year	Total Production TPROD X 10^{-6} (millions of short tons)	Number of Man-Days Worked MNDY X 10^{-6} (millions of man-days)	Weighted-Average Seam Thickness ST (inches)	Percent of Coal Loaded Mechanically (PMECH)	Weighted-Average Employment AEMPL	Average Production AP X 10^{6} (short tons)	Number of Inspections Per Mine Under CMHSA MACT
1950	14.2044	2.08672	49.37	79.37	19	47347.9	0.0
1951	15.6201	2.27048	49.64	85.18	24	59392.2	0.0
1952	13.3159	1.76203	49.63	84.70	20	56185.2	0.0
1953	12.6715	1.58740	48.90	87.27	21	61214.8	0.0
1954	9.68518	1.11518	49.77	85.98	15	47946.4	0.0
1955	13.3428	1.36044	49.87	88.64	21	75382.8	0.0
1956	12.1479	1.20878	49.88	90.48	23	82638.8	0.0
1957	10.4159	0.981419	50.30	90.76	19	71833.6	0.0
1958	8.31189	0.766626	49.98	89.32	17	65967.3	0.0
1959	9.16640	0.791449	50.10	90.17	15	65474.3	0.0
1960	8.78158	0.753049	50.27	92.23	18	75703.3	0.0
1961	8.43522	0.655503	50.29	92.34	17	79577.4	0.0
1962	8.99840	0.648004	50.26	92.98	18	91820.4	0.0
1963	10.0101	0.674383	50.36	94.61	20	108805.0	0.0
1964	10.2002	0.688937	50.44	95.50	21	114609.0	0.0
1965	11.2121	0.681546	60.28	96.92	24	145612.0	0.0
1966	13.0398	0.727246	57.82	97.98	24	157106.0	0.0
1967	15.1186	0.790808	58.13	98.61	39	269975.0	0.0
1968	16.3141	0.771030	58.56	99.12	43	332941.0	0.0
1969	18.5608	0.907879	58.39	99.23	71	530308.0	0.0
1970	18.8981	1.01886	59.17	99.66	93	629936.0	5.15924
1971	12.6930	1.04662	57.93	99.88	102	453322.0	10.4678
1972	16.2833	1.30545	58.78	99.95	128	581546.0	29.2330
1973	16.1651	1.36326	59.40	100.0	156	673547.0	42.6833
1974	14.3983	1.43719	58.04	100.0	158	575932.0	52.0947
1975	14.2409	1.75779	56.93	99.94	172	508604.0	39.1479

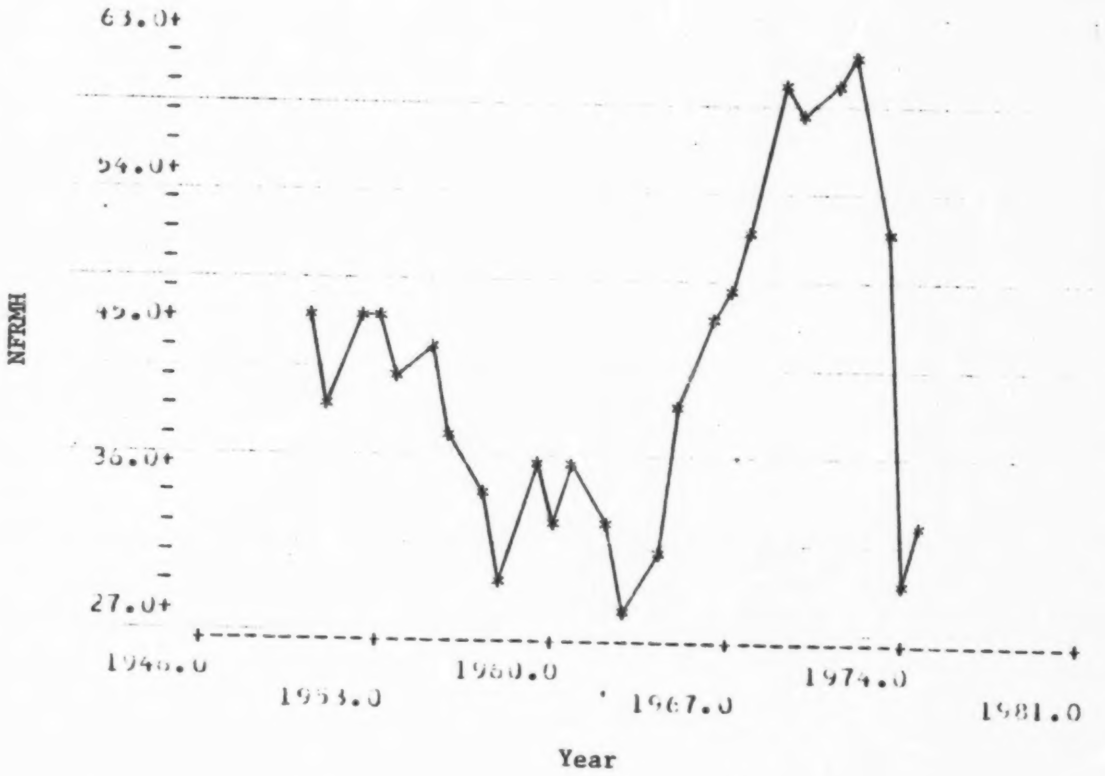


Figure 179. Trend of Nonfatal Injury Rate Per Million Man-Hours: Ohio (1950 Through 1975)

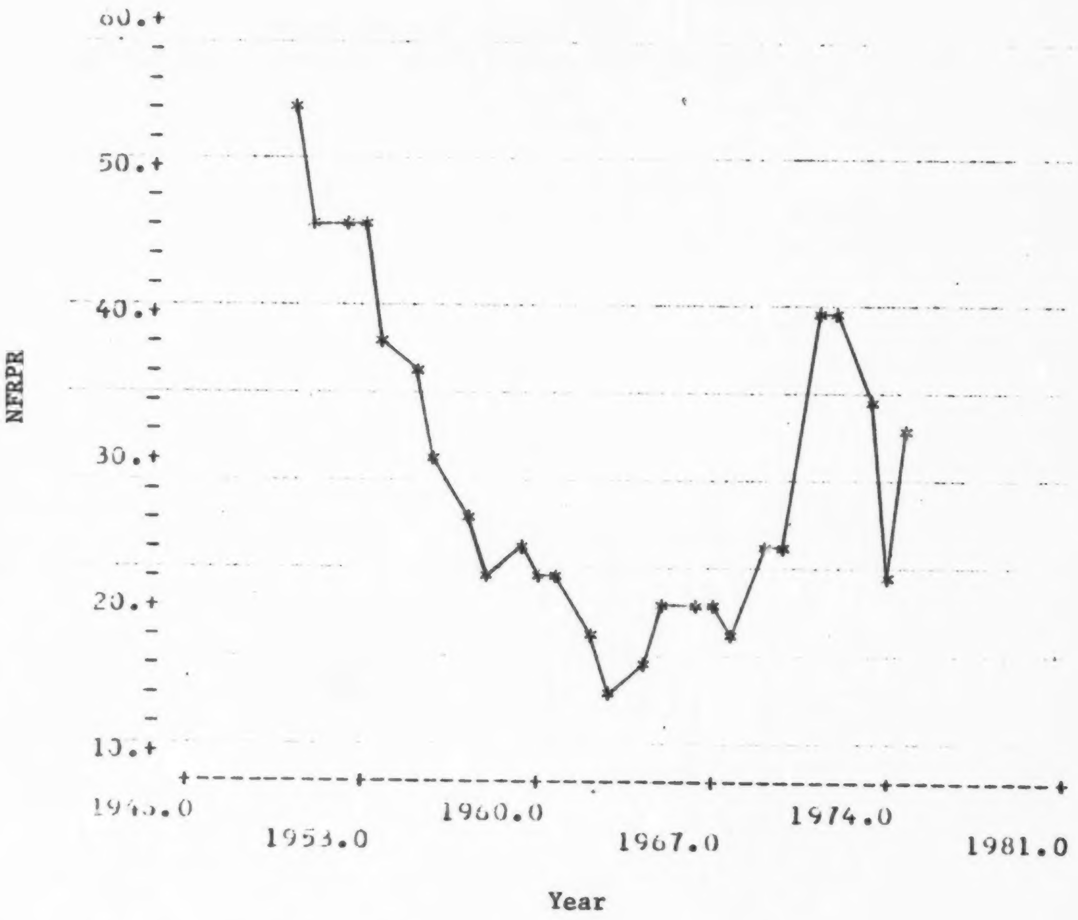


Figure 180. Trend of Nonfatal Injury Rate Per Million Tons: Ohio (1950 Through 1975)

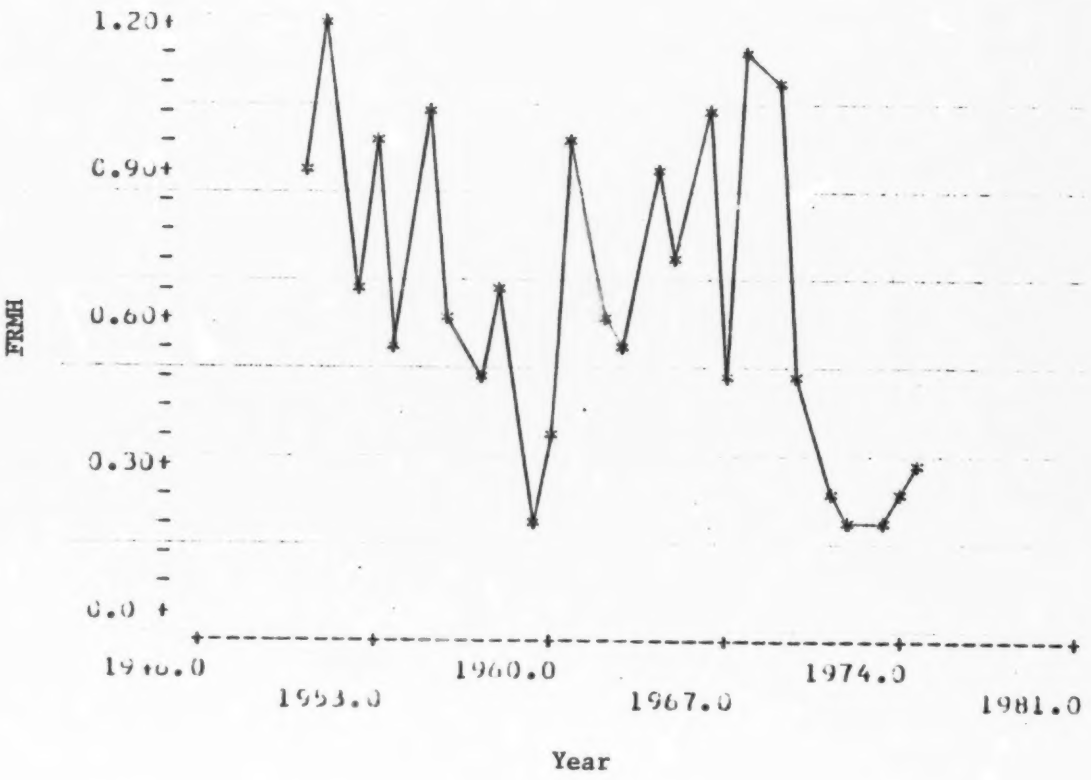


Figure 181. Trend of Fatal Injury Rate Per Million Man-Hours: Ohio (1950 Through 1975)

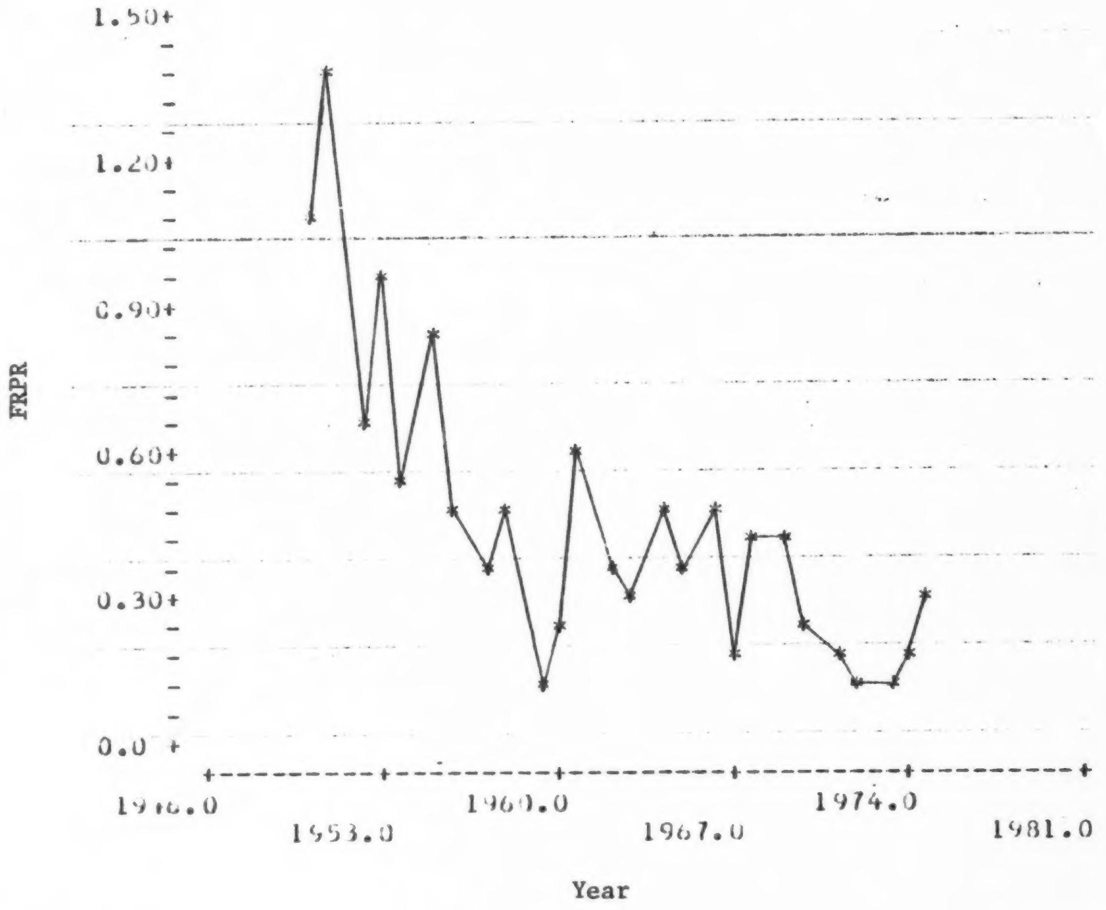


Figure 182. Trend of Fatal Injury Rate Per Million Tons: Ohio (1950 Through 1975)

Table 109

Piecewise Regression Results for Injury Rates: Ohio

Equation Dependent Variable	Constant	X_1	$X_2(X_1-10)$ Join Point of 1959	$X_3(X_1-14)$ Join Point of 1963	$X_4(X_1-20)$ Join Point of 1969	$X_5(X_1-23)$ Join Point of 1972	R^2	S	F-Statistic
69 NFRMH	46.91 (2.03)	-1.273 (0.224) ****		5.977 (0.664) ****	-3.93 (1.62) **	-11.88 (2.50) ****	0.89	3.70	$41.86_{(4,21)}$
70 NFRPR	52.90 (2.00)	-2.78 (0.22) ****		4.24 (0.66) ****	3.94 (1.60) **	-9.70 (2.46) ****	0.91	3.65	$50.33_{(4,21)}$
71 FRMH	1.06 (0.16)	-0.06 (0.02) ***	0.10 (0.04) ***		-0.18 (0.05) ****		0.50	0.25	$7.38_{(3,22)}$
72 FRPR	1.20 (0.11)	-0.09 (0.01) ****	0.08 (0.02) ****				0.74	0.17	$32.54_{(2,23)}$

Significance Levels:
** Significant at the 95.0 percent confidence level (two-tail test)
*** Significant at the 98.0 percent confidence level (two-tail test)
**** Significant at the 99.0 percent confidence level (two-tail test)

99.0 percent, respectively. Nonfatal injury rates per million tons (NFRPR) show a declining trend from 1950 through 1963, an increasing trend from 1963 through 1972 (with the trend becoming steeper in 1968 to 1969), and finally a declining trend thereafter (Figure 180). Again, piecewise regression confirms that these breaks in trend in 1963, 1969, and 1972 are significant at confidence levels of 99.0, 95.0, and 99.0 percent, respectively. Fatal injury rates per million man-hours (FRMH) show an overall declining trend from 1950 through 1959, an increasing trend through 1969, then a generally declining trend thereafter (Figure 181). These breaks in trend in 1959 and 1969 are significant at the 99.0 and 95.0 percent confidence levels, respectively. Fatal injury rates per million tons (FRPR) show a declining trend from 1950 through 1959, then a generally level trend thereafter (Figure 182). Piecewise regression shows this break in trend to be significant at the 98.0 percent confidence level (Table 109).

The trends for weighted-average seam thickness and average production (Figures 60 and 61) have been described in the section on Ohio in Chapter III. Percent of coal loaded mechanically (Figure 183) rises steeply from 1950 (79.4) through 1970 (99.9), then levels off through 1975. Weighted-average employment (Figure 184) has a level trend from 1950 through 1966, then rises steeply through 1975.

Results of Regressions for 1950 Through 1975

Results for regressions of the injury rates are shown in Tables 110 and 111. The appropriate pairwise correlation matrices are shown in Tables 112 and 113. The greatest pairwise correlation is between AEMPL and MACT (0.93). Only the OLS regression of NFRPR (Equation 74) has

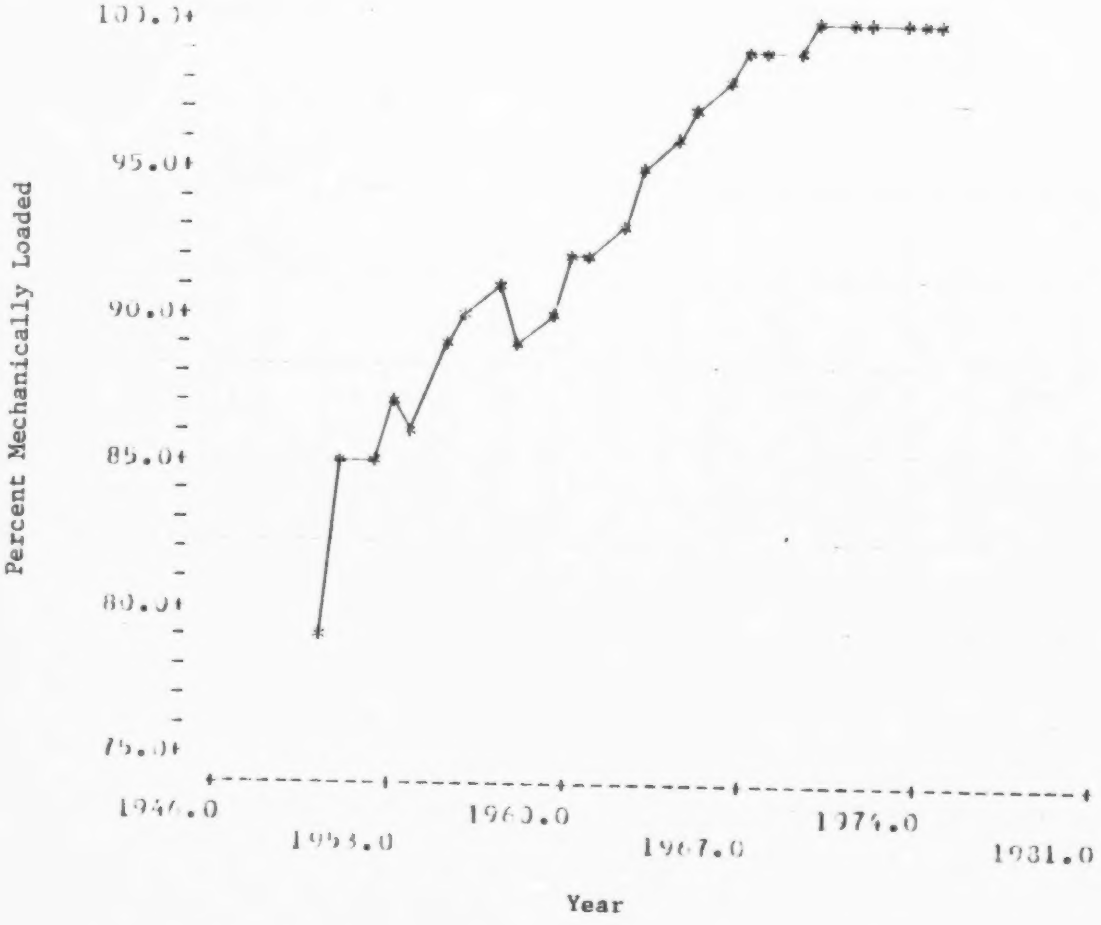


Figure 183. Trend of Percent Mechanically Loaded: Ohio (1950 Through 1975)

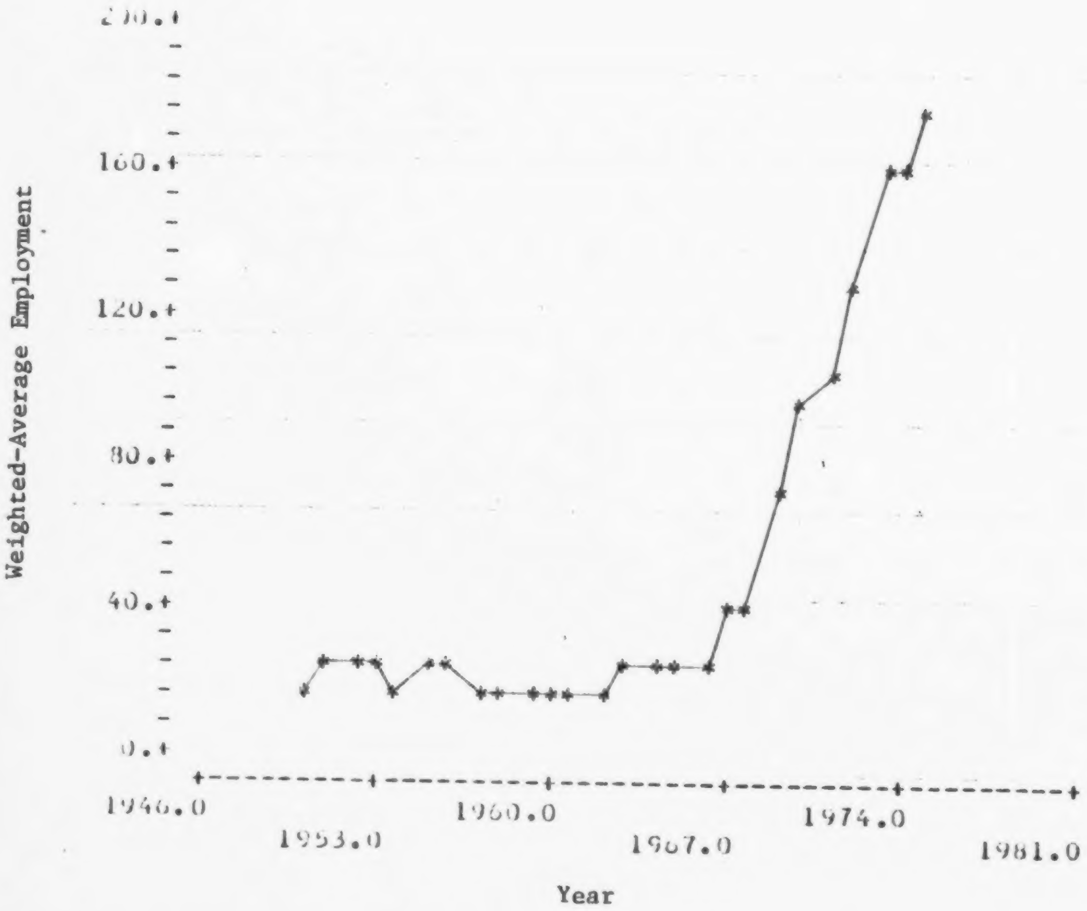


Figure 184. Trend of Weighted-Average Employment: Ohio (1950 Through 1975)

Table 110

Results of Regressions for Injury Model: Ohio
(1950 Through 1975)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-correlation (Durbin-Watson Statistic)	F-Statistic
73(OLS) NFRMI	94.028 (28.684)	1.300 (0.571) **	-1.415 (0.365) #####	61.599 (12.393) #####		-0.550 (0.113) #####	0.76	5.46	None(1.51)	$16.40_{(4,21)}$
74(OLS) NFRPR	224.285 (21.699)	0.953 (0.485) *	-2.767 (0.331) #####		0.318 (0.070) #####	-0.510 (0.197) ####	0.82	5.02	+(1.40)	$24.08_{(4,21)}$
75(CORC) NFRPR	72.269 (73.145)	0.083 (0.470)	-0.636 (0.797)		0.213 (0.083) ####	-0.443 (0.200) ###	0.82	4.53	None(1.69)	$23.21_{(4,20)}$
76(OLS) FRMI	1.007 (1.492)	0.028 (0.297)	-0.019 (0.019)	-0.050 (0.644)		-0.012 (0.006) ##	0.36	0.28	None(2.17)	$3.01_{(4,21)}$
77(OLS) FRPR	4.468 (0.949)	0.018 (0.021)	-0.054 (0.014) #####		0.002 (0.003)	-0.007 (0.009)	0.59	0.22	None(2.35)	$7.58_{(4,21)}$

Significance Levels:
* Significant at the 90.0 percent confidence level (two-tail test)
** Significant at the 95.0 percent confidence level (two-tail test)
Significant at the 95.0 percent confidence level (one-tail test)
Significant at the 97.5 percent confidence level (one-tail test)
Significant at the 99.0 percent confidence level (one-tail test)
Significant at the 99.5 percent confidence level (one-tail test)

Table 111

Ninety-Five Percent Confidence Intervals for Coefficients in Ohio Regressions of Injury Model (1950 Through 1975)

Equation Dependent Variable	ST		PMECH		AP		AEMPL		MACT	
73(OLS) NFRMH	0.11	2.49	-2.17	-0.66	35.82	87.38			-0.79	-0.31
74(OLS) NFRPR	-0.06	1.96	-3.46	-2.08			0.17	0.46	-0.92	-0.10
75(CORC) NFRPR	-0.90	1.06	-2.30	1.03			0.04	0.39	-0.86	-0.03
76(OLS) FRMH	-0.59	0.65	-0.06	0.02	-1.39	1.29			-0.02	0.00
77(OLS) FRPR	-0.03	0.06	-0.08	-0.02			-0.00	0.01	-0.03	0.01

Table 112

Pairwise Correlation Matrix for ST, PMECH, AP, and MACT: Ohio (1950 Through 1975)

	ST	PMECH	AP	MACT
ST	1.0000	0.85364	0.83180	0.50606
PMECH	0.85364	1.0001	0.78767	0.50847
AP	0.83180	0.78767	1.0000	0.74458
MACT	0.50606	0.50847	0.74458	1.0000

Table 113

Pairwise Correlation Matrix for ST, PMECH, AEMPL, and MACT: Ohio (1950 Through 1975)

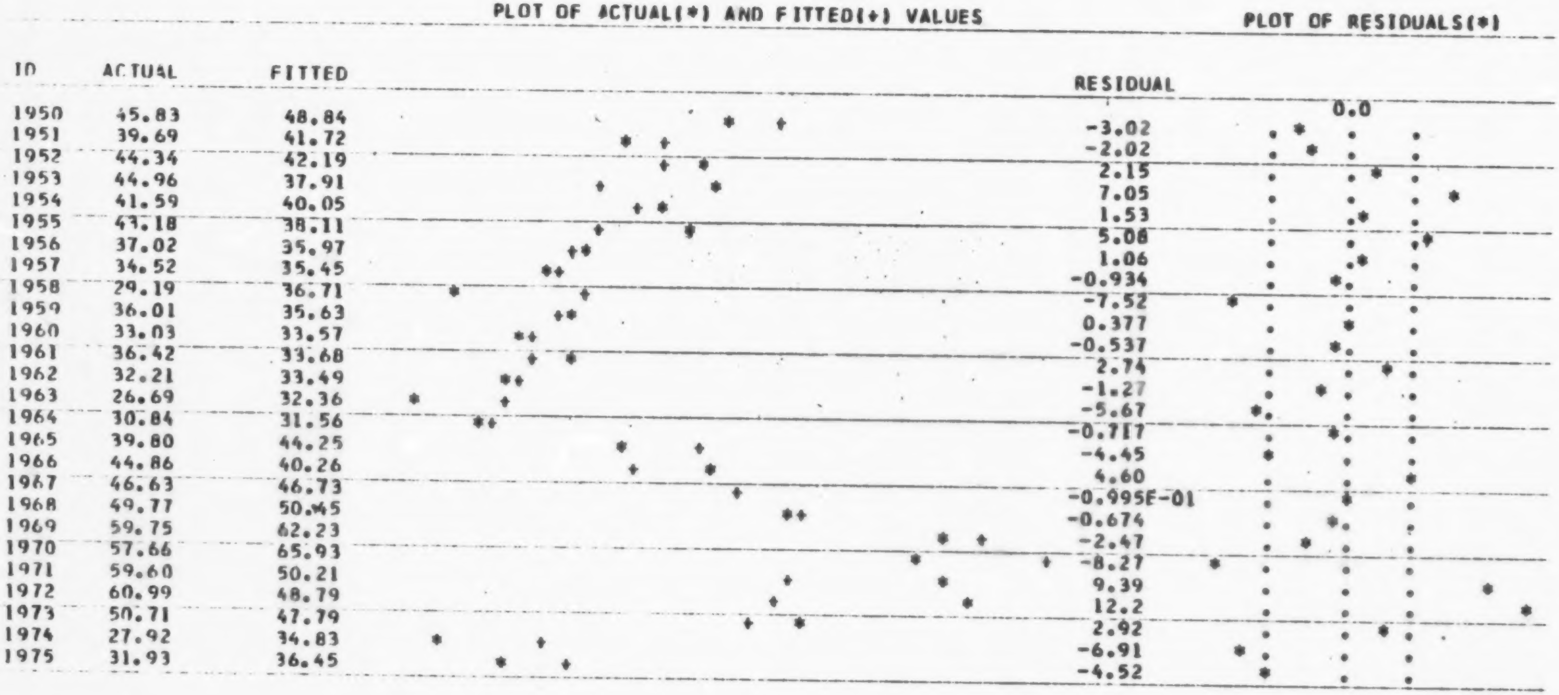
	ST	PMECH	AEMPL	MACT
ST	1.0000	0.85364	0.68337	0.50606
PMECH	0.85364	1.0001	0.66300	0.50847
AEMPL	0.68337	0.66300	1.0000	0.92608
MACT	0.50606	0.50847	0.92608	1.0000

the problem of autocorrelation, but this is remedied with the CORC regression. Appropriate plots are shown in Figures 185 through 188. There is no evidence of heteroskedasticity.

The regression of NFRMH (Equation 73) results in all coefficients being significant, with the coefficient of ST having an unexpected sign. The percent of variance explained is 76.0. For NFRPR (Equation 75), 82.0 percent of the variance is explained, and the coefficients of AEMPL and MACT are significant with the expected signs. The regression of FRMH (Equation 76) explains 36.0 percent of the variance; only the coefficient of MACT is significant. The regression of FRPR (Equation 77) explains 59.0 percent of the variance, with only the coefficient of PMECH being significant. All coefficients of ST are positive, but only that in the regression of NFRMH is significant. All coefficients of PMECH are negative; for NFRMH and FRPR, these coefficients are significant. The coefficient of AP is positive as expected and significant for NFRMH; it is negative and not significant for FRMH. The coefficients of AEMPL are positive for both FRPR and NFRPR, but significant only for the latter. All coefficients of MACT are negative, as expected, and significant for all except FRPR.

Results of Regressions for 1950 Through 1969 and Predictions of Productivity

In this section, results of regressions on data through 1969 are presented, and predictions of injury rates are made assuming there is no CMHSA. The trends of the independent variables, as discussed previously, suggest that they are not affected by the Mine Act. The results of regressions using data through 1969 are given in Tables 114 and 115. The pairwise correlation matrices are presented in Tables 116



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                         PLOT OF ACTUAL(*) AND FITTED(+) VALUES                PLOT OF RESIDUALS(*)
ID     ACTUAL     FITTED                                          RESIDUAL
1950   45.83      48.84                                           -3.02
1951   39.69      41.72                                           -2.02
1952   44.34      42.19                                           2.15
1953   44.96      37.91                                           7.05
1954   41.59      40.05                                           1.53
1955   43.18      38.11                                           5.08
1956   37.02      35.97                                           1.06
1957   34.52      35.45                                           -0.934
1958   29.19      36.71                                           -7.52
1959   36.01      35.63                                           0.377
1960   33.03      33.57                                           -0.537
1961   36.42      33.68                                           2.74
1962   32.21      33.49                                           -1.27
1963   26.69      32.36                                           -5.67
1964   30.84      31.56                                           -0.717
1965   39.80      44.25                                           -4.45
1966   44.86      40.26                                           4.60
1967   46.63      46.73                                           -0.995E-01
1968   49.77      50.45                                           -0.674
1969   59.75      62.23                                           -2.47
1970   57.66      65.93                                           -8.27
1971   59.60      50.21                                           9.39
1972   60.99      48.79                                           12.2
1973   50.71      47.79                                           2.92
1974   27.92      34.83                                           -6.91
1975   31.93      36.45                                           -4.52
```
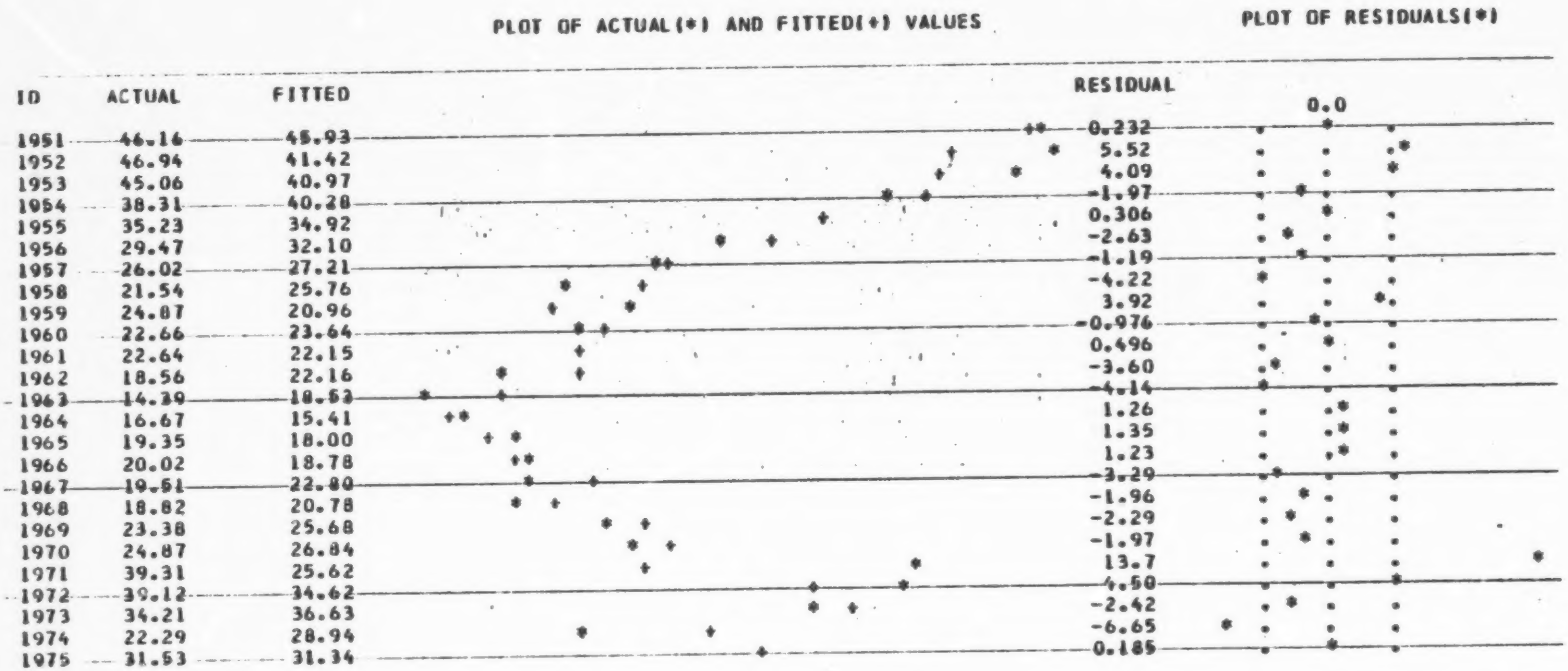

Figure 185. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1950 Through 1975: Ohio (OLS)



```
ID      ACTUAL     FITTED                RESIDUAL
1951    46.16      45.93                 0.232
1952    46.94      41.42                 5.52
1953    45.06      40.97                 4.09
1954    38.31      40.28                 -1.97
1955    35.23      34.92                 0.306
1956    29.47      32.10                 -2.63
1957    26.02      27.21                 -1.19
1958    21.54      25.76                 -4.22
1959    24.87      20.96                 3.92
1960    22.66      23.64                 -0.976
1961    22.64      22.15                 0.496
1962    18.56      22.16                 -3.60
1963    14.39      18.53                 -4.14
1964    16.67      15.41                 1.26
1965    19.35      18.00                 1.35
1966    20.02      18.78                 1.23
1967    19.51      22.80                 -3.29
1968    18.82      20.78                 -1.96
1969    23.38      25.68                 -2.29
1970    24.87      26.84                 -1.97
1971    39.31      25.62                 13.7
1972    39.12      34.62                 4.50
1973    34.21      36.63                 -2.42
1974    22.29      28.94                 -6.65
1975    31.53      31.34                 0.185
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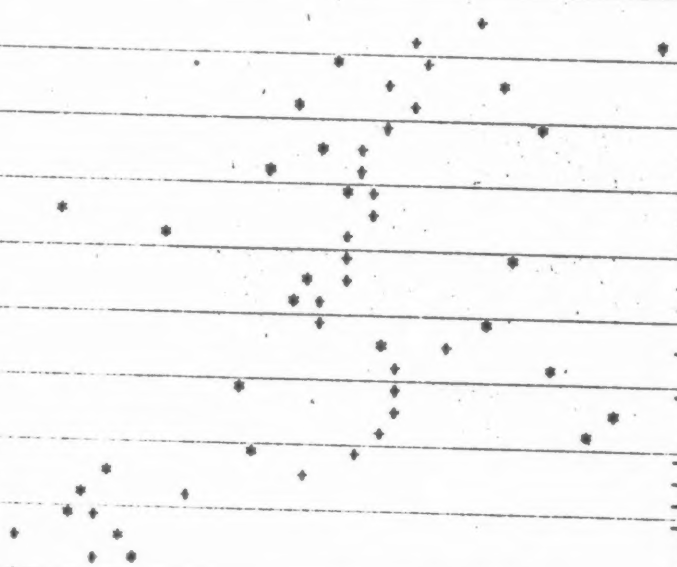
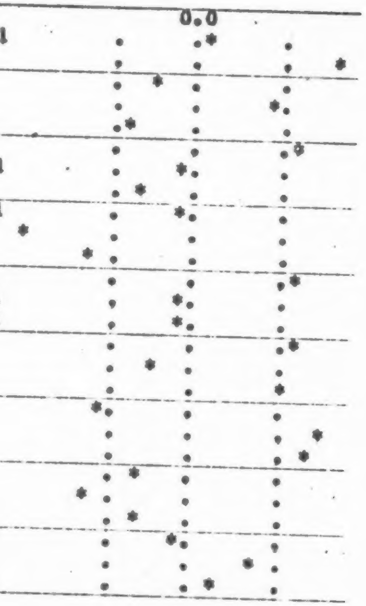
Figure 186. Plots for Nonfatal Injury Rate Per Million Tons, 1950 Through 1975: Ohio (CORC)

PLOT OF ACTUAL(*) AND FITTED(+) VALUES



PLOT OF RESIDUALS(*)



ID	ACTUAL	FITTED	RESIDUAL
1950	0.8985	0.8826	0.160E-01
1951	1.211	0.7795	0.432
1952	0.6385	0.7885	-0.150
1953	0.9449	0.7191	0.226
1954	0.[illegible]604	0.7686	-0.208
1955	1.011	0.7196	0.291
1956	0.6205	0.6847	-0.642E-01
1957	0.5095	0.6917	-0.182
1958	0.6522	0.7103	-0.581E-01
1959	0.1579	0.6976	-0.540
1960	0.3320	0.6628	-0.331
1961	0.9535	0.6611	0.292
1962	0.5787	0.6475	-0.688E-01
1963	0.5561	0.6186	-0.625E-01
1964	0.9072	0.6037	0.304
1965	0.7336	0.8504	-0.117
1966	1.031	0.7609	0.270
1967	0.4742	0.7520	-0.278
1968	1.135	0.7511	0.384
1969	1.101	0.7343	0.367
1970	0.4907	0.6812	-0.190
1971	0.2389	0.5876	-0.349
1972	0.1915	0.3788	-0.187
1973	0.1834	0.2294	-0.460E-01
1974	0.2609	0.8353E-01	0.177
1975	0.2844	0.2121	0.723E-01

Figure 187. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1975: Ohio (OLS)

```
                                   PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(*)
 ID      ACTUAL       FITTED
                                                                        RESIDUAL
1950     1.056        1.120
1951     1.408        0.8227                                           -0.642E-01
1952     0.6759       0.8397                                            0.586
1953     0.9470       0.6902                                           -0.164
1954     0.5163       0.7623                                            0.257
1955     0.8244       0.6338                                           -0.246
1956     0.4939       0.5391                                            0.191
1957     0.3840       0.5228                                           -0.452E-01
1958     0.4812       0.5903                                           -0.139
1959     0.1091       0.5423                                           -0.109
1960     0.2277       0.4409                                           -0.433
1961     0.5928       0.4331                                           -0.213
1962     0.3334       0.4003                                            0.160
1963     0.2997       0.3185                                           -0.669E-01
1964     0.4902       0.2742                                           -0.188E-01
1965     0.3568       0.3815                                            0.216
1966     0.4601       0.2800                                           -0.247E-01
1967     0.1984       0.2844                                            0.180
1968     0.4291       0.2734                                           -0.860E-01
1969     0.4310       0.3256                                            0.156
1970     0.2117       0.3292                                            0.105
1971     0.1576       0.2783                                           -0.118
1972     0.1228       0.2180                                           -0.121
1973     0.1237       0.1955                                           -0.952E-01
1974     0.2084       0.1109                                           -0.718E-01
1975     0.2809       0.2135                                            0.975E-01
                                                                        0.674E-01
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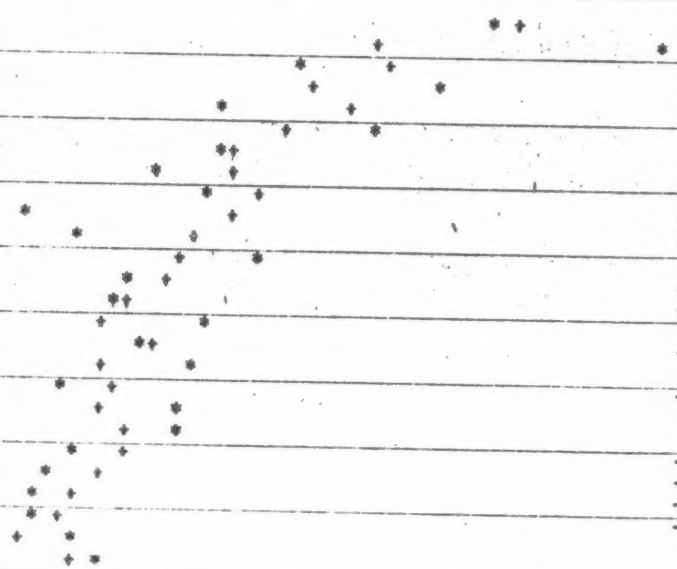


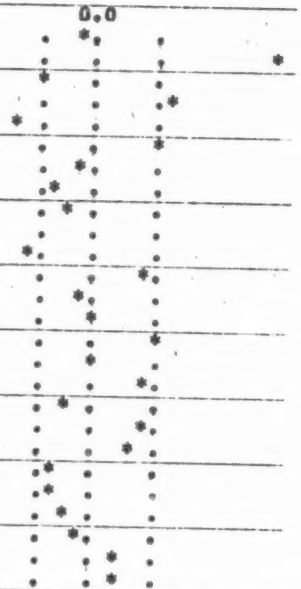


Figure 188. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1975: Ohio (OLS)

Table 114

Results of Regressions for Injury Model: Ohio (1950 Through 1969)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	R^2	S	Auto-correlation (Durbin-Watson statistic)	F-Statistic
78(OLS) NFRMH	96.319 (21.646)	1.246 (0.411) ****	-1.407 (0.265) #####	58.261 (11.935) #####		0.80	3.85	None(1.65)	$21.60_{(3,16)}$
79(OLS) NFRPR	225.849 (18.008)	0.940 (0.414)	-2.767 (0.262) #####		0.276 (0.095) ####	0.91	3.94	None(1.50)	$51.25_{(3,16)}$
80(OLS) FRMH	1.919 (1.573)	0.017 (0.030)	-0.024 (0.019)	1.157 (0.867)		0.20	0.28	None(2.61)	$1.31^{‡}_{(3,16)}$
81(OLS) FRPR	4.724 (1.076)	0.012 (0.025)	-0.055 (0.016) #####		0.008 (0.006)	0.53	0.24	None(2.51)	$6.00_{(3,16)}$

‡The equation is not significant at the 95.0 percent confidence level or greater.

Significance Levels:

** Significant at the 95.0 percent confidence level (two-tail test)
**** Significant at the 99.0 percent confidence level (two-tail test)
Significant at the 99.0 percent confidence level (one-tail test)
Significant at the 99.5 percent confidence level (one-tail test)

Table 115

Ninety-Five Percent Confidence Intervals for Coefficients in Ohio Regressions of Injury Model (1950 Through 1969)

Equation Dependent Variable	ST		PMECH		AP		AEMPL	
78(OLS) NFRMH	0.37	2.12	-1.97	-0.85	32.96	83.56		
79(OLS) NFRPR	0.06	1.82	-3.32	-2.21			0.07	0.48
80(OLS) FRMH	-0.05	0.08	-0.06	0.02	-0.68	3.00		
81(OLS) FRPR	-0.04	0.07	-0.09	-0.02			-0.00	0.02

and 117. The greatest correlations (0.77) are between ST and PMECH and ST and AP. The least satisfactory results are for FRMH, since the equation is not statistically significant at the 95.0 percent confidence level and only 20.0 percent of the variance is explained. The results of the other regressions are good, with 80.0, 91.0, and 53.0 percent of the variance explained for NFRMH, NFRPR, and FRPR, respectively. Plots of residuals and actual and fitted values are shown in Figures 189 through 192. There is no evidence for the presence of heteroskedasticity. The coefficients of ST are, again, all unexpectedly positive and significant for the nonfatal injury rates. The coefficients of PMECH are all negative and significant in all regressions except FRMH. The coefficients of AP are positive but significant only for NFRMH; those of AEMPL are also positive but significant only for NFRPR.

The regression results were used to predict possible injury rates in the absence of the CMHSA. These are reported in Table 118. With only two exceptions (NFRMH and NFRPR in 1972), actual injury rates are less than predicted rates; however, the differences are statistically significant at the 95.0 percent confidence level only for NFRMH in 1973 through 1975 and FRMH for 1971 through 1975.

Predictions derived using the results of the regressions with data through 1975 are shown in Tables 119 and 120. For NFRMH and NFRPR, actual rates are significantly less than predicted rates in 1970 and 1973 through 1975; in 1972, the actual rate falls within the prediction interval but lower than the mean; and in 1971, the actual rate significantly exceeds the predicted value. For FRMH, actual rates are significantly less than predicted rates in 1970 through 1973, while

Table 116

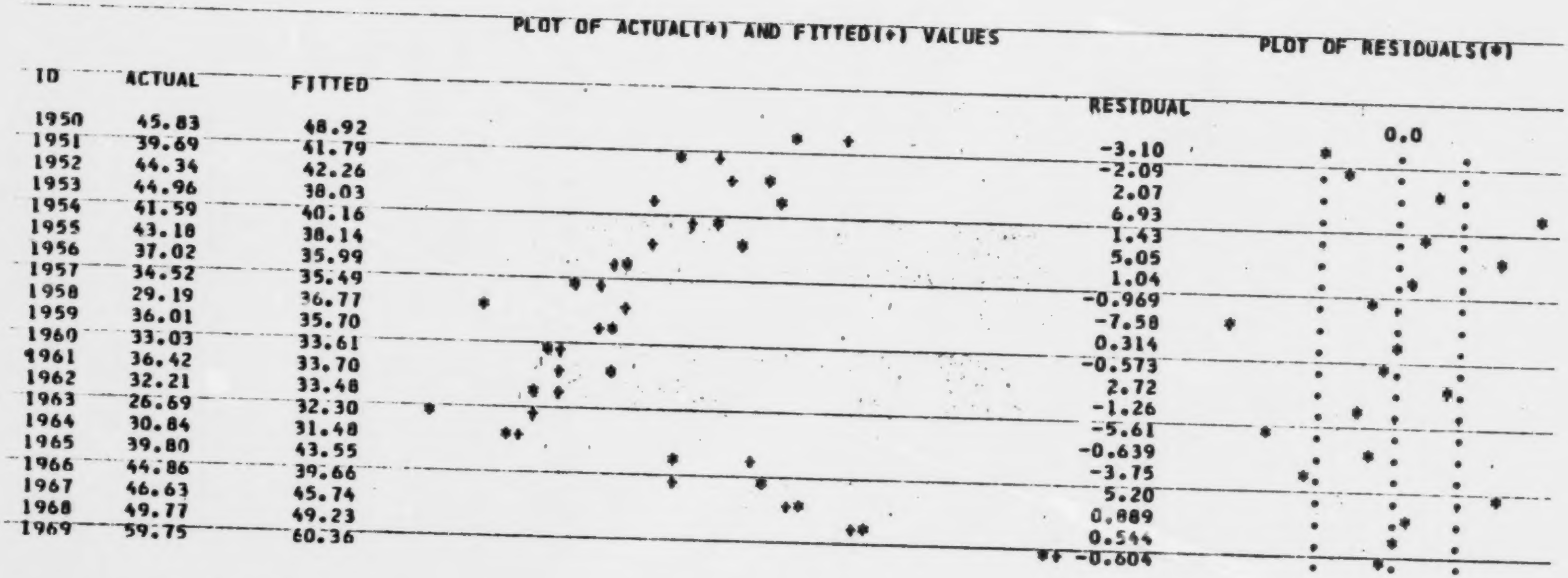
Pairwise Correlation Matrix for ST, PMECH, and AP: Ohio (1950 Through 1969)

	ST	PMECH	AP
ST	1.0000	0.77358	0.76913
PMECH	0.77358	1.0001	0.70503
AP	0.76913	0.70503	1.0000

Table 117

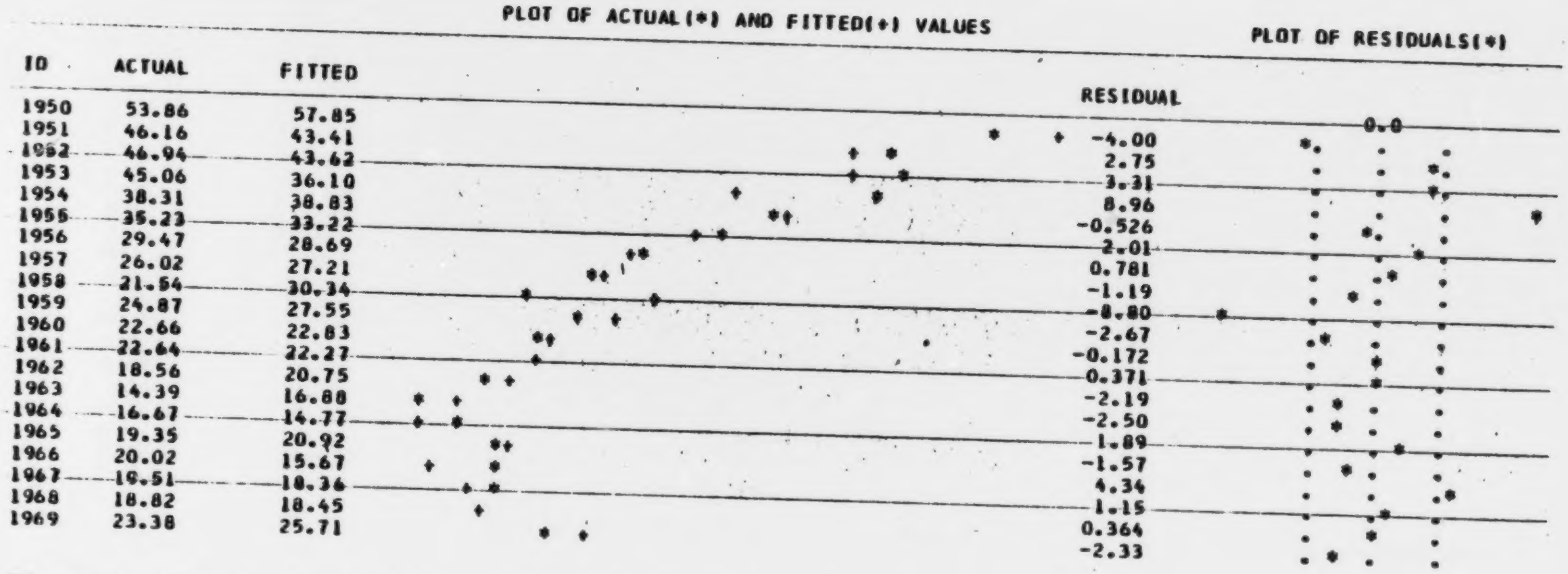
Pairwise Correlation Matrix for ST, PMECH, and AEMPL: Ohio (1950 Through 1969)

	ST	PMECH	AEMPL
ST	1.0000	0.77358	0.68184
PMECH	0.77358	1.0001	0.56245
AEMPL	0.68184	0.56245	1.0000



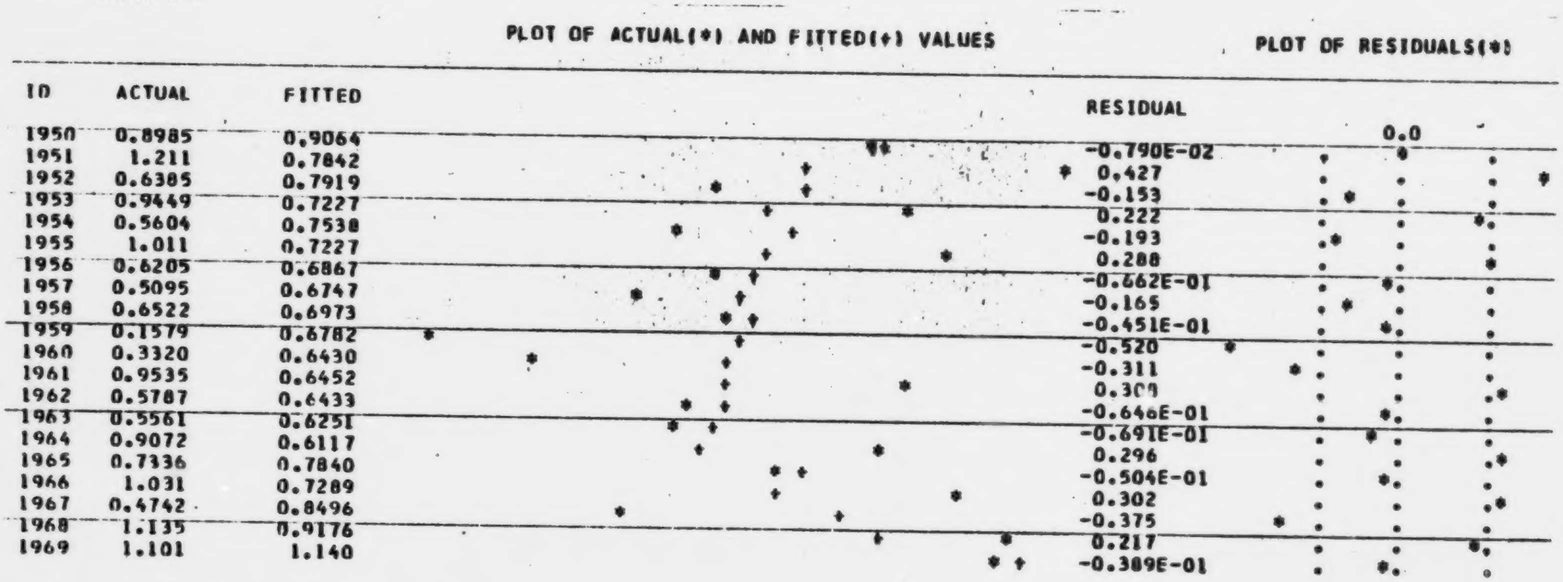
ID	ACTUAL	FITTED	RESIDUAL
1950	45.83	48.92	-3.10
1951	39.69	41.79	-2.09
1952	44.34	42.26	2.07
1953	44.96	38.03	6.93
1954	41.59	40.16	1.43
1955	43.18	38.14	5.05
1956	37.02	35.99	1.04
1957	34.52	35.49	-0.969
1958	29.19	36.77	-7.58
1959	36.01	35.70	0.314
1960	33.03	33.61	-0.573
1961	36.42	33.70	2.72
1962	32.21	33.48	-1.26
1963	26.69	32.30	-5.61
1964	30.84	31.48	-0.639
1965	39.80	43.55	-3.75
1966	44.86	39.66	5.20
1967	46.63	45.74	0.889
1968	49.77	49.23	0.544
1969	59.75	60.36	-0.604

Figure 189. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1950 Through 1969: Ohio (OLS)



ID	ACTUAL	FITTED	RESIDUAL
1950	53.86	57.85	-4.00
1951	46.16	43.41	2.75
1952	46.94	43.62	3.31
1953	45.06	36.10	8.96
1954	38.31	38.83	-0.526
1955	35.23	33.22	2.01
1956	29.47	28.69	0.781
1957	26.02	27.21	-1.19
1958	21.54	30.34	-8.80
1959	24.87	27.55	-2.67
1960	22.66	22.83	-0.172
1961	22.64	22.27	0.371
1962	18.56	20.75	-2.19
1963	14.39	16.88	-2.50
1964	16.67	14.77	1.89
1965	19.35	20.92	-1.57
1966	20.02	15.67	4.34
1967	19.51	18.36	1.15
1968	18.82	18.45	0.364
1969	23.38	25.71	-2.33

Figure 190. Plots for Nonfatal Injury Rate Per Million Tons, 1950 Through 1969: Ohio (OLS)



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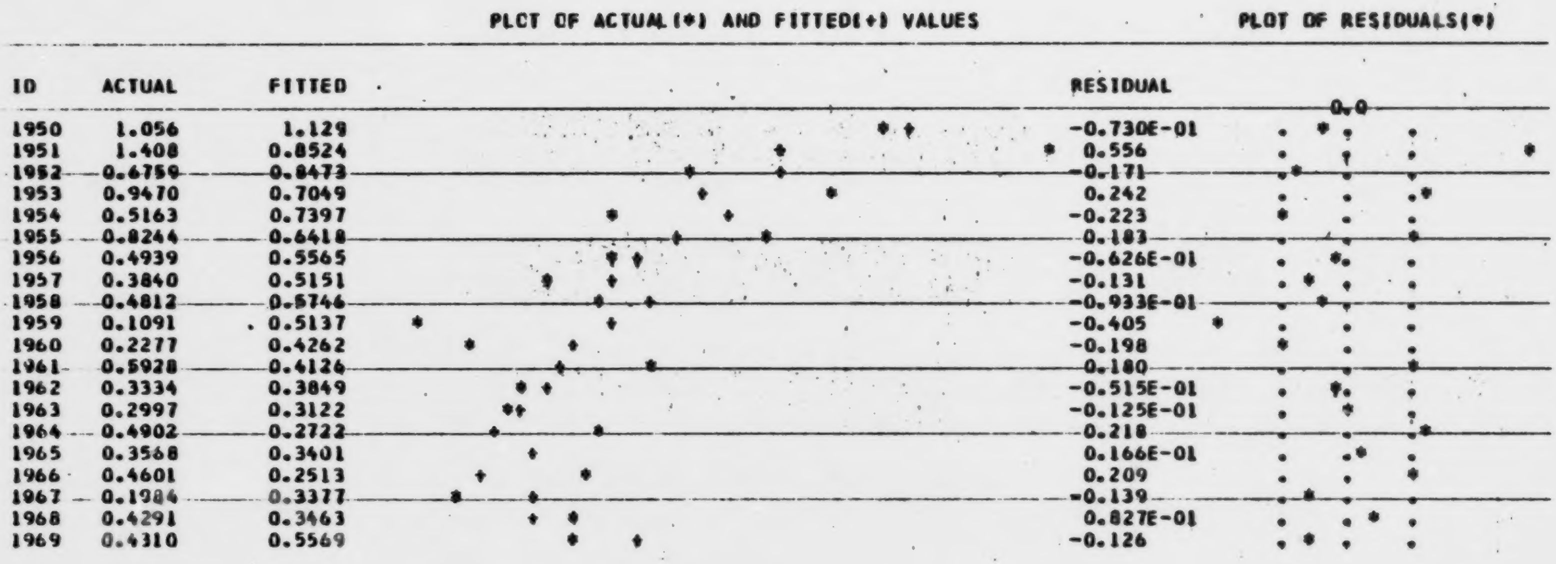
                                 PLOT OF ACTUAL(*) AND FITTED(+) VALUES                PLOT OF RESIDUALS(*)
ID     ACTUAL        FITTED                                                 RESIDUAL
                                                                                                 0.0
1950   0.8985        0.9064                                                 -0.790E-02
1951    1.211        0.7842                                                  0.427
1952   0.6385        0.7919                                                 -0.153
1953   0.9449        0.7227                                                  0.222
1954   0.5604        0.7538                                                 -0.193
1955    1.011        0.7227                                                  0.288
1956   0.6205        0.6867                                                 -0.662E-01
1957   0.5095        0.6747                                                 -0.165
1958   0.6522        0.6973                                                 -0.451E-01
1959   0.1579        0.6782                                                 -0.520
1960   0.3320        0.6430                                                 -0.311
1961   0.9535        0.6452                                                  0.308
1962   0.5787        0.6433                                                 -0.646E-01
1963   0.5561        0.6251                                                 -0.691E-01
1964   0.9072        0.6117                                                  0.296
1965   0.7336        0.7840                                                 -0.504E-01
1966    1.031        0.7289                                                  0.302
1967   0.4742        0.8496                                                 -0.375
1968    1.135        0.9176                                                  0.217
1969    1.101         1.140                                                 -0.389E-01
```

Figure 191. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1969: Ohio (OLS)



```
                         PLCT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                        RESIDUAL
                                                                                 0.0
1950    1.056       1.129                                         -0.730E-01
1951    1.408       0.8524                                         0.556
1952    0.6759      0.8473                                        -0.171
1953    0.9470      0.7049                                         0.242
1954    0.5163      0.7397                                        -0.223
1955    0.8244      0.6418                                         0.183
1956    0.4939      0.5565                                        -0.626E-01
1957    0.3840      0.5151                                        -0.131
1958    0.4812      0.5746                                        -0.933E-01
1959    0.1091      0.5137                                        -0.405
1960    0.2277      0.4262                                        -0.198
1961    0.5928      0.4126                                         0.180
1962    0.3334      0.3849                                        -0.515E-01
1963    0.2997      0.3122                                        -0.125E-01
1964    0.4902      0.2722                                         0.218
1965    0.3568      0.3401                                         0.166E-01
1966    0.4601      0.2513                                         0.209
1967    0.1984      0.3377                                        -0.139
1968    0.4291      0.3463                                         0.827E-01
1969    0.4310      0.5569                                        -0.126
```

Figure 192. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1969: Ohio (OLS)

Table 118

Comparison of Predicted Levels of Injury Rates Based on Multiple Regressions With Actual Injury Rates: Ohio‡

Injury Rate		Year					
		1970	1971	1972	1973	1974	1975
NFRMH(OLS)	Predicted	66.53	54.39	62.82	68.88	61.50	56.28
		(±12.35)	(±9.94)	(±11.59)	(±13.04)	(±11.63)	(±10.85)
	Actual	57.66	59.60	60.99	50.71	27.92	31.93
NFRPR(OLS)	Predicted	31.32	32.03	39.81	47.97	47.25	50.23
		(±14.03)	(±15.77)	(±20.00)	(±24.93)	(±25.77)	(±28.86)
	Actual	24.87	39.31	39.12	34.21	22.29	31.53
FRMH(OLS)	Predicted	1.26	1.03	1.19	1.31	1.17	1.07
		(±0.90)	(±0.72)	(±0.84)	(±0.95)	(±0.85)	(±0.79)
	Actual	0.49	0.24	0.19	0.18	0.26	0.28
FRPR(OLS)	Predicted	0.72	0.76	0.97	1.19	1.19	1.29
		(±0.84)	(±0.94)	(±1.19)	(±1.49)	(±1.54)	(±1.72)
	Actual	0.21	0.16	0.12	0.12	0.21	0.28

---

‡Prediction intervals for a 95.0 percent confidence level are given in parentheses.

Table 119

Effect of MACT on Nonfatal Injury Rates: Ohio

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Nonfatal Injuries Per Million Man-Hours								
NFKMH	1969	-0.785	-0.550	-0.315	0				62.23				59.75	
	1970				5.15924	1.63	2.84	4.05	65.93	67.56	68.77	69.98	57.66	4.1
	1971				10.4678	3.30	5.76	8.22	50.21	53.51	59.27	58.43	59.60	15.3
	1972				29.2330	9.21	16.08	22.95	48.79	58.00	64.87	71.74	60.99	24.8
	1973				42.6833	13.45	23.48	33.51	47.79	61.24	71.27	81.30	50.71	32.9
	1974				52.0947	16.41	28.65	40.89	34.83	51.24	63.48	75.72	27.92	28.7
	1975				39.1479	12.33	21.53	30.73	36.45	48.78	57.98	67.18	31.93	37.1
						Nonfatal Injuries Per Million Tons								
NFRPR	1969	-0.860	-0.443	-0.026	0				25.68				23.38	
	1970				5.15924	0.13	2.29	4.44	26.84	26.97	29.13	31.28	24.87	7.9
	1971				10.4678	0.27	4.64	9.00	25.62	25.89	30.26	34.62	39.31	15.3
	1972				29.2330	0.76	12.95	25.14	34.62	35.38	47.57	59.76	39.12	27.2
	1973				42.6833	1.11	18.91	36.71	36.63	37.74	55.54	73.34	34.21	34.0
	1974				52.0947	1.35	23.08	44.80	28.94	30.29	52.02	73.74	22.29	44.4
	1975				39.1479	1.02	17.34	33.67	31.34	32.36	48.68	65.01	31.53	35.6

Table 120

Effect of MACT on Fatal Injury Rates: Ohio

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Fatal Injuries Per Million Man-Hours								
FRMH	1969	-0.024	-0.012	0.000	0				0.73				1.10	
	1970				5.15924	0	0.06	0.12	0.68	0.68	0.74	0.80	0.49	8.1
	1971				10.4678	0	0.13	0.25	0.59	0.59	0.72	0.84	0.24	18.1
	1972				29.2330	0	0.35	0.70	0.38	0.38	0.73	1.08	0.19	47.9
	1973				42.6833	0	0.51	1.02	0.23	0.23	0.74	1.25	0.18	68.9
	1974				52.0947	0	0.63	1.25	0.08	0.08	0.71	1.33	0.26	88.7
	1975				39.1479	0	0.47	0.94	0.21	0.21	0.68	1.15	0.28	69.1
						Fatal Injuries Per Million Tons								
FRPR	1969	-0.026	-0.007	0.012	0				0.33				0.43	
	1970				5.15924	-0.06	0.04	0.13	0.33	0.27	0.37	0.46	0.21	10.8
	1971				10.4678	-0.13	0.07	0.27	0.28	0.15	0.35	0.55	0.16	20.0
	1972				29.2330	-0.35	0.20	0.76	0.22	<0	0.42	0.98	0.12	47.6
	1973				42.6833	-0.51	0.30	1.11	0.20	<0	0.50	1.31	0.12	60.0
	1974				52.0947	-0.63	0.36	1.35	0.11	<0	0.47	1.46	0.21	76.6
	1975				39.1479	-0.47	0.27	1.02	0.21	<0	0.48	1.23	0.28	56.3

in 1974 and 1975, actual rates fall within prediction intervals but less than the mean. For FRPR, the actual rate is significantly less than predicted without MACT only in 1970; in all other years, actual values fall within prediction intervals but less than the mean. Tables 119 and 120 also show the percentage decreases in injury rates based on predictions by the model as compared to the predicted rates after eliminating the effects of MACT. For example, in 1975, the prediction of NFRMH is lower than the predicted rate without MACT by 37.1 percent. The corresponding comparisons for the other injury rates are: NFRPR is reduced by 35.6 percent, FRMH is reduced by 69.1 percent, and FRPR is reduced by 56.3 percent.

Summary

The relationships of the independent variables to the injury rates may be summarized as follows. For NFRMH and NFRPR: (1) weighted-average seam thickness is positively related and significant for NFRMH; (2) percent mechanically loaded is negatively related and significant for NFRMH; (3) the mine-size variables are positively related and significant; and (4) the Mine-Act variable is negatively related and significant. For FRMH: (1) weighted-average seam thickness is positively related and not significant; (2) percent mechanically loaded is negatively related but not significant; (3) average production is negatively related but not significant; and (4) the Mine-Act variable is negatively realted and significant. For FRPR: (1) weighted-average seam thickness is positively related and not significant; (2) percent mechanically loaded is negatively related and significant; (3) weighted-average employment is positively related and not significant; and (4) the Mine-Act variable is negatively related but not significant.

The effects of each variable on the injury rates may be summarized as follows: (1) an increase in ST of one inch increases NFRMH by 1.3, NFRPR by 0.08, FRMH by 0.03, and FRPR by 0.02; (2) an increase in PMECH of one percent decreases NFRMH by 1.4, NFRPR by 0.64, FRMH by 0.02, and FRPR by 0.02; (3) an increase in AP of one million tons increases NFRMH by 61.6 and decreases FRMH by 0.05; (4) an increase in AEMPL by ten increases NFRPR by 2.1 and FRPR by 0.02; and (5) an increase in the value of the Mine-Act variable by one decreases NFRMH by 0.55, NFRPR by 0.44, FRMH by 0.01, and FRPR by 0.01.

The results suggest that the Mine Act may have reduced injury rates. The least evidence for this conclusion exists for FRPR.

Eastern Kentucky

Data and Trends of Variables

The data used are shown in Table 121. The state data on injuries, total production and average production, man-days worked, weighted-average seam thickness, and weighted-average employment were obtained from the Kentucky Department of Mines and Minerals Annual Report for 1950 through 1959 and 1964 through 1975. The derivation of ST data for 1964 through 1975 is presented in the section on eastern Kentucky in Chapter III; problems with lack of data in 1960 through 1963 were also discussed. Again, data before 1964 are for rail-connected mines only.

The trends over time of the accident rates studied are shown in Figures 193 through 196. Nonfatal injury rates per million man-hours (NFRMH) show a slightly decreasing trend with wide variations. There does not appear to be a break in trend; piecewise regression results indicate there is no significant break in trend in 1969 (Table 122). Nonfatal injury rates per million tons (NFRPR) show a declining trend from 1950 to 1970; after 1970 the trend is for increasing rates. Piecewise regression results indicate this break in trend in 1969 is significant at the 99.0 percent confidence level (Table 122). Fatal injury rates per million man-hours (FRMH) have an overall declining trend from 1950 through 1975. No break in trend is evident in 1969 (Table 122) or in any other year. Fatal injury rates per million tons (FRPR) have a trend that is very similar to FRMH; there is no significant break in trend in 1969 (Table 122). There were no disaster fatalities in the mines in the sample.

Table 121

Data for Eastern Kentucky Injury Model: Underground Rail-Connected Mines

Year	Number of Nonfatal Injuries NFTL	Nonfatal Injury Rate Per Million Man-Hours NFRMH	Nonfatal Injury Rate Per Million Tons NFRPR	Total Number of Fatal Injuries FTL	Number of Disaster Fatalities DFTL	Fatal Injury Rate Per Million Man-Hours FRMH	Fatal Injury Rate Per Million Tons FRPR
1950	2242	42.7927	70.0167	53	0	1.01160	1.65517
1951	2154	40.1297	61.3956	95	0	1.76988	2.70779
1952	1938	48.8678	67.9349	37	0	0.932977	1.29700
1953	1857	51.3866	63.6898	34	0	0.940843	1.16610
1954	1385	53.2824	57.8808	29	0	1.11566	1.21194
1955	1319	47.6551	50.3430	82	0	2.96263	3.12974
1956	1256	47.9639	48.3985	27	0	1.03107	1.04041
1957	933	47.0935	42.5140	28	0	1.41331	1.27587
1958	603	38.8694	32.2544	19	0	1.22474	1.01631
1959	546	43.6371	32.9315	10	0	0.799214	0.603141
1964	452	43.6954	27.4570	6	0	0.580028	0.364473
1965	394	37.1611	22.8826	11	0	1.03749	0.638854
1966	556	52.1236	30.3462	16	0	1.49996	0.873271
1967	587	53.8391	27.7448	21	0	1.92610	0.992574
1968	514	45.7588	23.0790	8	0	0.712200	0.359207
1969	472	39.6443	20.7930	10	0	0.839921	0.440530
1970	390	30.0376	17.8196	13	0	1.00126	0.593987
1971	684	54.1442	38.6437	9	0	0.712424	0.508470
1972	619	49.5003	33.7455	10	0	0.799683	0.545162
1973	720	49.7619	34.1838	9	0	0.622024	0.427297
1974	501	33.5285	26.7596	4	0	0.267693	0.213650
1975	731	47.3354	39.0310	10	0	0.675255	0.556790

Table 121 (Continued)

Year	Total Production TPROD X 10^{-6} (millions of short tons)	Number of Man-Days Worked MNDY X 10^{-6} (millions of man-days)	Weighted-Average Seam Thickness (inches)	Weighted-Average Seam Thickness, Adjusted ST (inches)	Percent of Coal Loaded Mechanically PMECH	Weighted-Average Employment AEMPL	Average Production AP X 10^{6} (short tons)	Number of Inspections Per Mine Under CMHSA MACT
1950	32.0209	6.54901	47.23	47.23	48.66	95	169423	0.0
1951	35.0840	6.70950	47.53	47.53	56.63	102	193834	0.0
1952	28.5273	4.95725	47.46	47.46	61.42	75	156744	0.0
1953	29.1570	4.51723	49.06	49.06	66.74	67	158462	0.0
1954	23.9285	3.24919	49.55	49.55	74.31	55	146801	0.0
1955	26.2003	3.45976	50.61	50.61	69.69	57	158790	0.0
1956	25.9512	3.27330	49.39	49.39	69.85	61	176539	0.0
1957	21.9457	2.47546	50.13	50.13	69.23	53	171451	0.0
1958	18.6951	1.93918	49.74	49.74	71.82	50	174721	0.0
1959	16.5799	1.56404	50.24	50.24	74.78	50	192789	0.0
1964	16.4621	1.29304	44.73	50.73	71.48	47	216607	0.0
1965	17.2183	1.32531	43.98	49.98	76.96	53	253211	0.0
1966	18.3219	1.33337	45.40	51.40	81.36	54	269440	0.0
1967	21.1571	1.36286	44.74	50.74	85.64	57	320562	0.0
1968	22.2713	1.40410	45.10	51.10	90.05	49	281915	0.0
1969	22.6999	1.48824	45.36	51.36	96.04	51	283749	0.0
1970	21.8860	1.62296	45.33	51.33	91.89	50	245910	5.15924
1971	17.7002	1.57912	44.88	50.88	95.06	52	213255	10.4678
1972	18.3432	1.56312	45.62	51.62	97.14	48	206103	29.2330
1973	21.0626	1.80861	45.56	51.56	98.39	57	242099	42.6833
1974	18.7222	1.86781	46.23	52.23	99.44	59	215198	52.0947
1975	17.9601	1.85115	45.45	51.45	99.61	60	211295	39.1479

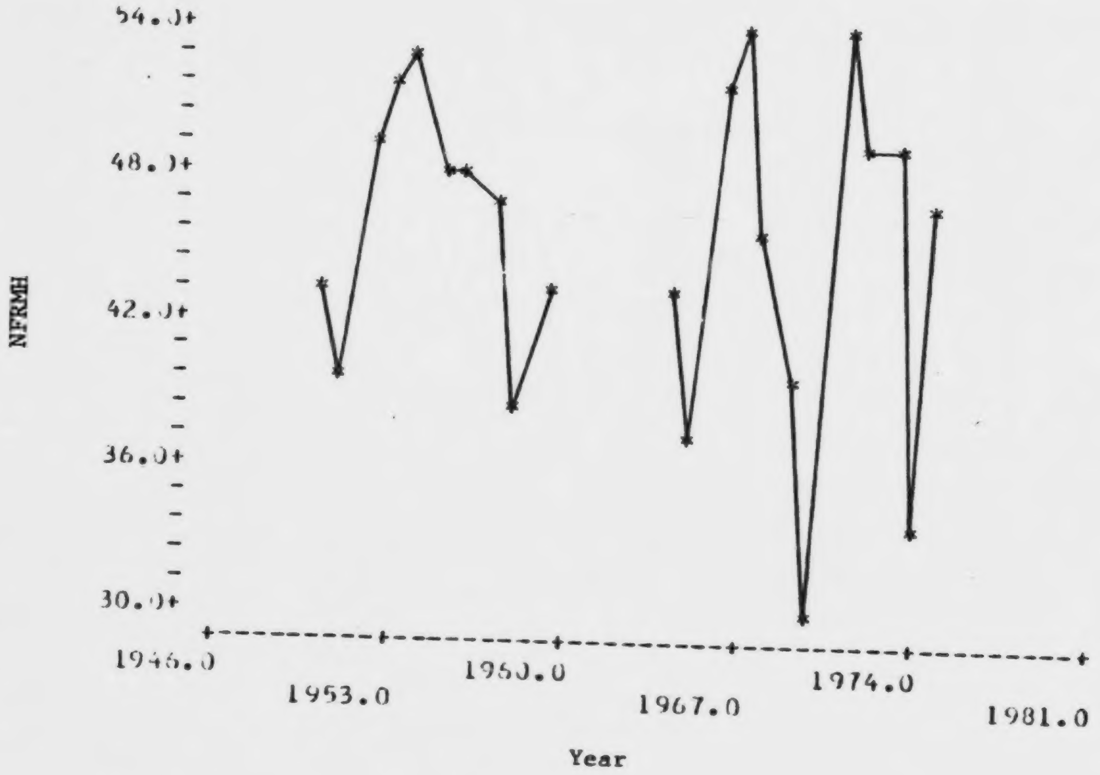


Figure 193. Trend of Nonfatal Injury Rate Per Million Man-Hours: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

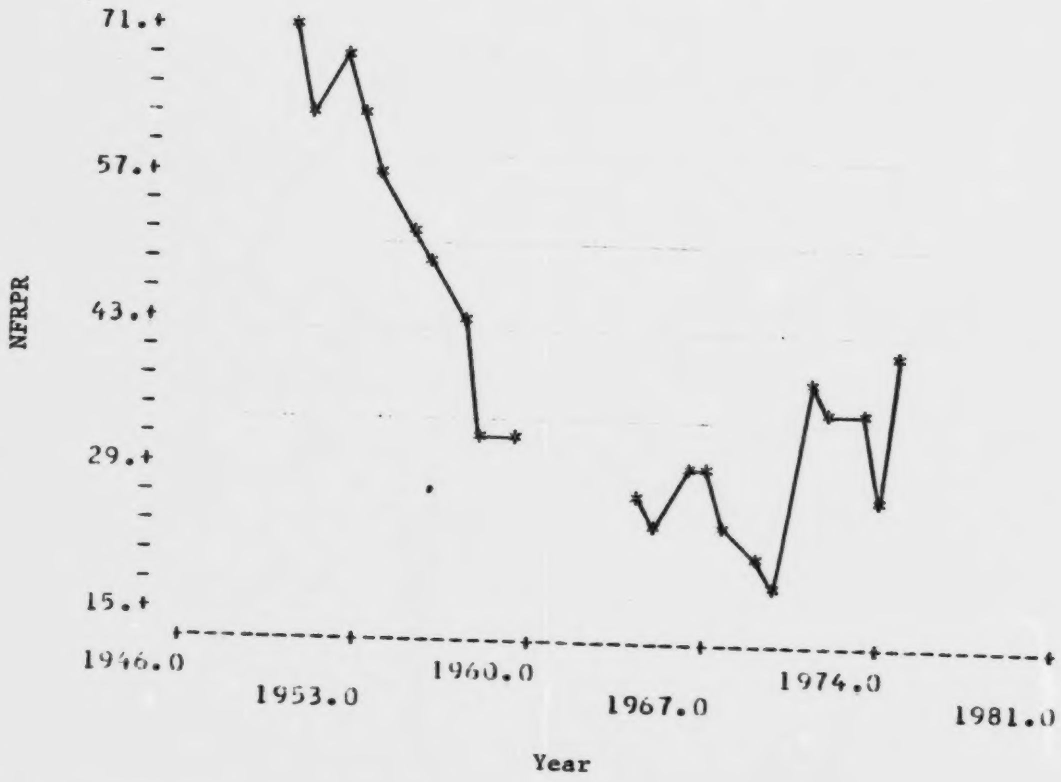


Figure 194. Trend of Nonfatal Injury Rate Per Million Tons: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

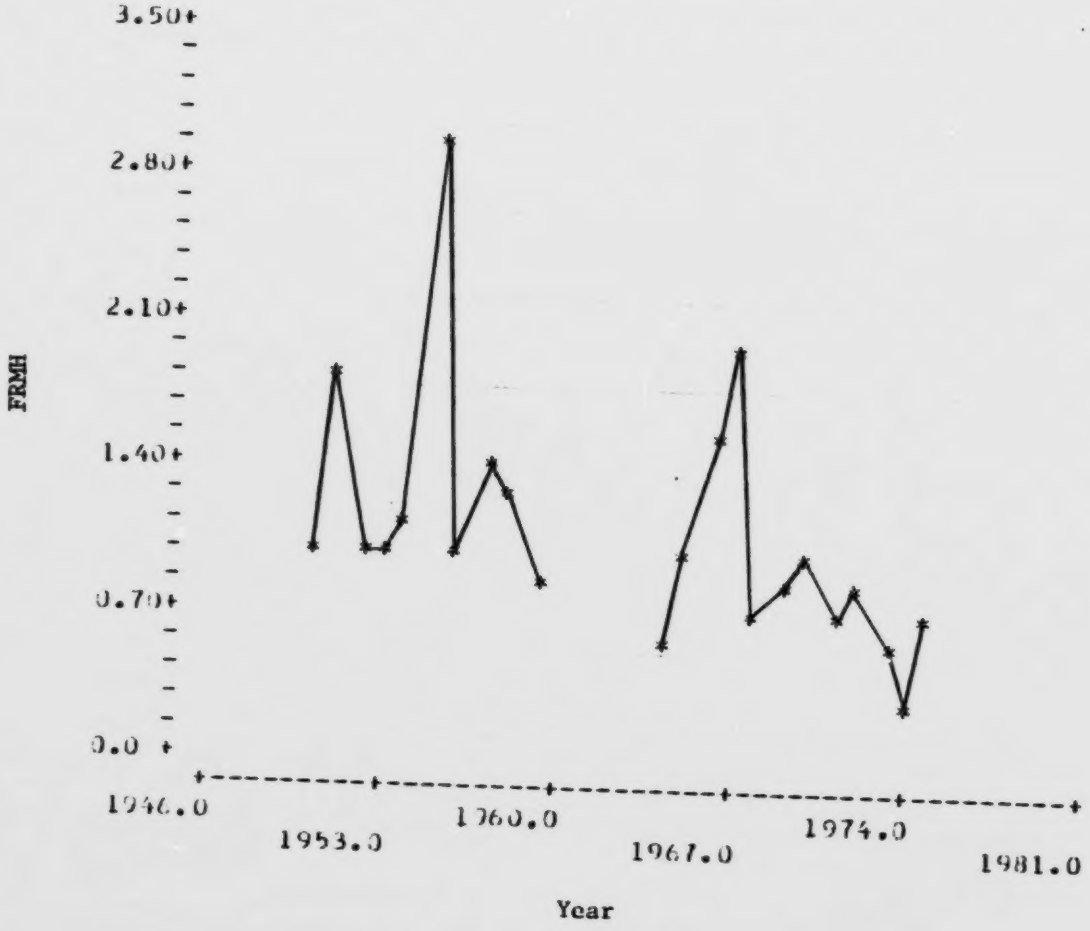


Figure 195. Trend of Fatal Injury Rate Per Million Man-Hours: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

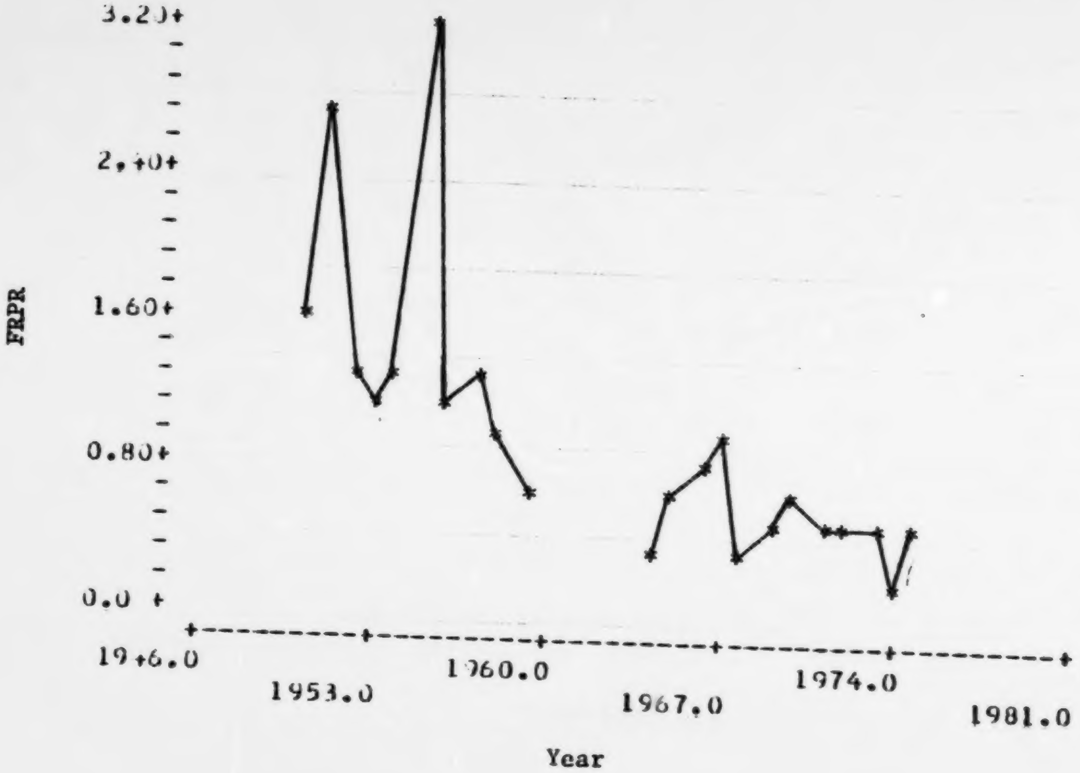


Figure 196. Trend of Fatal Injury Rate Per Million Tons: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

Table 122

Piecewise Regression Results for Injury Rates: Eastern Kentucky Underground Rail-Connected Mines

Equation Dependent Variable	Constant	X_1	$X_3(X_1-20)$ Join Point of 1969	R^2	S	F-Statistic
82 NFRMH	46.89 (3.17)	-0.12 (0.25)	0.17 (1.14)	0.02	6.90	$0.15^{‡}_{(2,19)}$
83 NFRPR	66.97 (3.04)	-2.41 (0.24) ****	5.77 (1.10) ****	0.85	6.62	$52.16_{(2,19)}$
84 FRMH	1.40 (0.24)	-0.02 (0.02)	-0.09 (0.09)	0.24	0.52	$3.00^{‡}_{(2,19)}$
85 FRPR	1.95 (0.24)	-0.08 (0.02) ****	0.08 (0.09)	0.54	0.52	$11.18_{(2,19)}$

‡The equation is not significant at the 95.0 percent confidence level or greater.

Significance Level: **** Significant at the 99.0 percent confidence level
(two-tail test)

Trends for weighted-average seam thickness and average production (Figures 74 and 76) are described in Chapter III. Percent of coal loaded mechanically (Figure 197) increases from 48.7 percent in 1950 to 99.6 percent in 1975. Breaks in trend in 1954, 1964, and 1969 are significant (99.0 percent confidence level). Weighted-average employment decreases from 1950 through 1954, has a level trend through 1972, then increases thereafter. These breaks are significant at the 99.0 and 98.0 percent confidence levels, respectively (Figure 198).

Results of Regressions for 1950 Through 1975

Results of regressions for the four injury rates are presented in Tables 123 and 124. The pairwise correlation matrices for the independent variables are shown in Tables 125 and 126. The greatest correlation is between PMECH and ST (0.90). Only the regression for NFRPR has the problem of autocorrelation; this was remedied in the CORC regression. Appropriate plots are presented in Figures 199 through 202. There is no evidence for the presence of heteroskedasticity.

The equation for NFRMH is not significant at the 95.0 percent confidence level, and the R^2 value is only 0.05. Thus, predictions based on this equation are to be viewed with little confidence. The equation for NFRPR explains 81.0 percent of the variance but has no significant variables. The coefficients of ST and PMECH are significant in Equation 90 (FRMH), and 52.0 percent of the variance is explained. Equation 92 for FRPR explains 70.0 percent of the variance, and all coefficients are significant at the 98.0 percent confidence level or greater except for MACT. Coefficients of ST are negative for the nonfatal injury rates but not significant; those for the fatal injury rates are

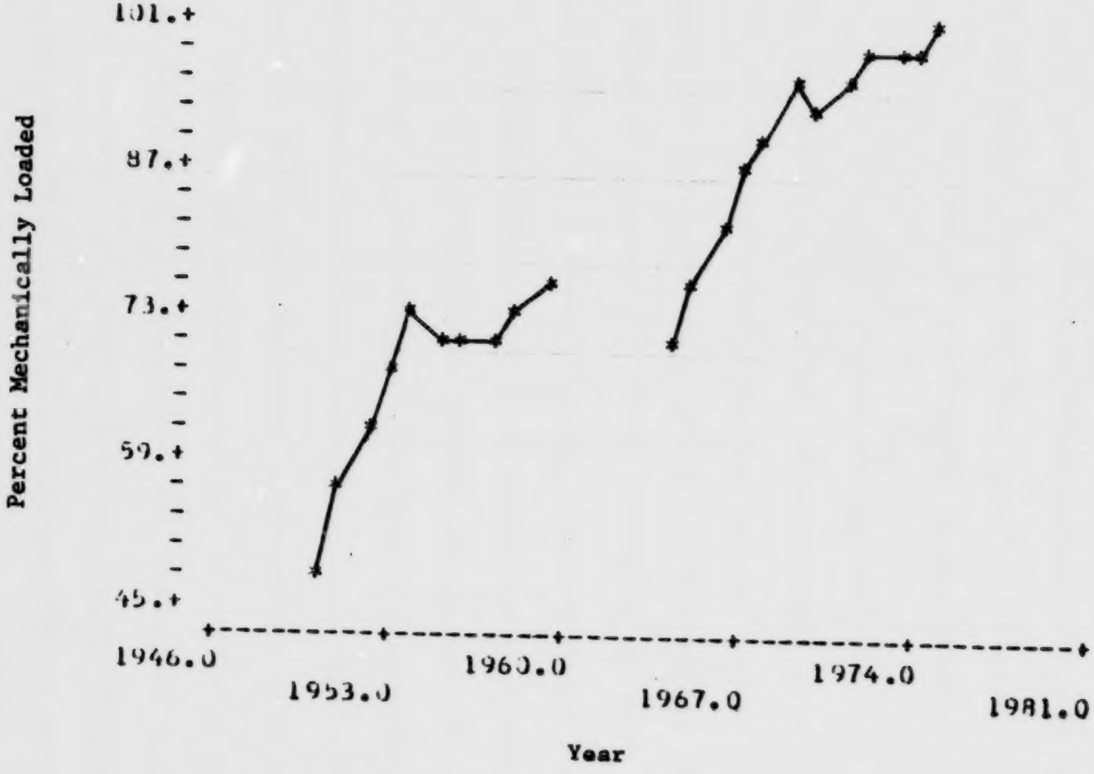


Figure 197. Trend of Percent Mechanically Loaded: Kentucky (1950 Through 1975)

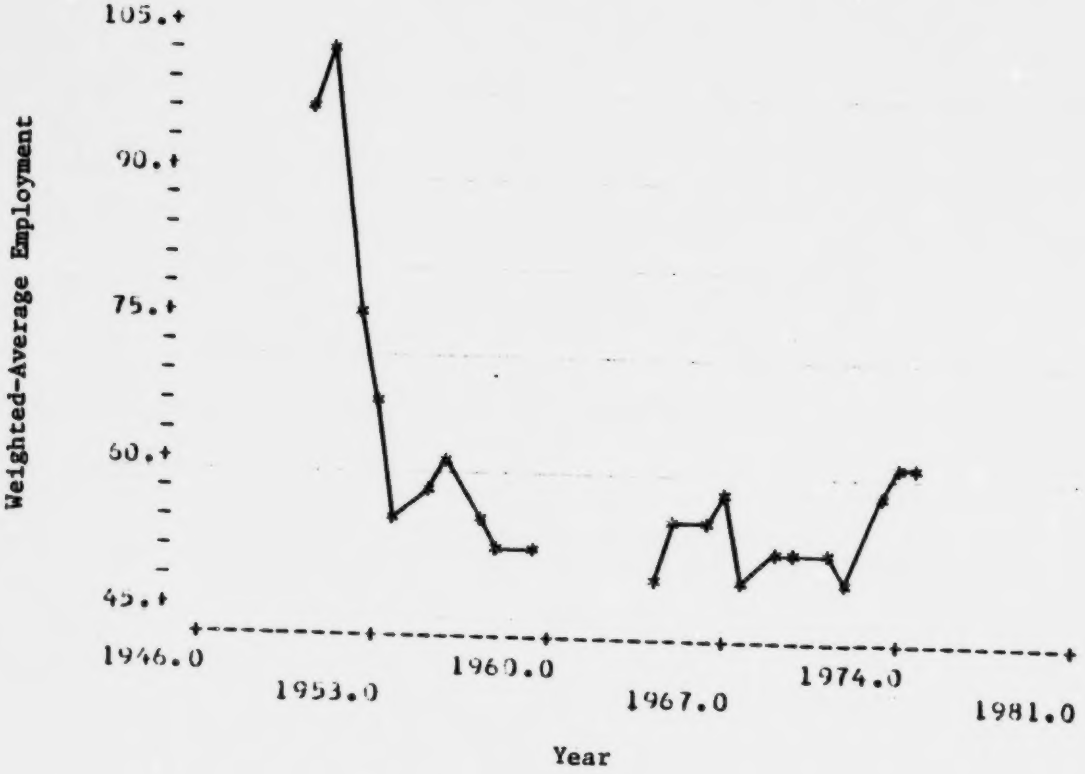


Figure 198. Trend of Weighted-Average Employment: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

Table 123

Results of Regressions for Injury Model: Eastern Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1975)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-correlation (Durbin-Watson Statistic)	F-Statistic
86(OLS) NFRMH	83.217 (112.009)	-0.919 (2.586)	0.205 (0.305)	-33.355 (46.041)		-0.112 (0.148)	0.05	7.12	None(1.86)	$0.21^{\ddagger}_{(4,17)}$
87(OLS) NFRPR	488.720 (205.015)	-8.523 (4.168) ##	-0.315 (0.334)		0.017 (0.271)	0.372 (0.192) *	0.76	8.77	+(1.28)	$13.29_{(4,17)}$
88(CORC) NFRPR	119.172 (147.438)	-2.014 (2.672)	0.300 (0.528)		-0.174 (0.252)	-0.109 (0.263)	0.81	7.37	None(2.29)	$16.09_{(4,15)}$
89(OLS) FRMH	-9.574 (8.233)	0.262 (0.190)	-0.033 (0.022) #	0.798 (3.384)		-0.009 (0.011)	0.31	0.53	None(2.44)	$1.93^{\ddagger}_{(4,17)}$
90(CORC) FRMH	-15.926 (7.864)	0.425 (0.182) **	-0.059 (0.022) ####	2.106 (2.930)		-0.003 (0.010)	0.52	0.46	None(2.07)	$3.99_{(4,15)}$

Table 123(Continued)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-correlation (Durbin-Watson Statistic)	F-Statistic
91(OLS) FRPR	-19.399 (12.229)	0.428 (0.249)	-0.040 (0.020) ##		0.036 (0.016) **	-0.010 (0.011)	0.59	0.52	None(1.85)	$6.07_{(4,17)}$
92(CORC) FRPR	-25.472 (10.689)	0.579 (0.220) ***	-0.061 (0.020) #####		0.041 (0.015) ***	-0.007 (0.011)	0.70	0.46	None(1.99)	$8.79_{(4,15)}$

‡The equation is not significant at the 95.0 percent confidence level or greater.

Significance Levels:
* Significant at the 90.0 percent confidence level (two-tail test)
** Significant at the 95.0 percent confidence level (two-tail test)
*** Significant at the 98.0 percent confidence level (two-tail test)
# Significant at the 90.0 percent confidence level (one-tail test)
## Significant at the 95.0 percent confidence level (one-tail test)
#### Significant at the 99.0 percent confidence level (one-tail test)
##### Significant at the 99.5 percent confidence level (one-tail test)

Table 124

Ninety-Five Percent Confidence Intervals for Coefficients in Eastern Kentucky Regressions of Injury Model: Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1975)

Equation Dependent Variable	ST		PMECH		AP		AEMPL		MACT	
86(OLS) NFRMH	-6.38	4.54	-0.44	0.85	-130.48	63.81			-0.42	0.20
87(OLS) NFRPR	-17.32	0.27	-1.02	0.39			-0.55	0.59	-0.03	0.78
88(CORC) NFRPR	-17.23	13.20	-0.83	1.43			-0.71	0.36	-0.67	0.45
89(OLS) FRMH	-0.14	0.66	-0.08	0.01	-6.34	7.94			-0.03	0.01
90(CORC) FRMH	0.04	0.81	-0.11	-0.01	-4.14	8.35			-0.02	0.02
91(OLS) FRPR	-0.10	0.95	-0.08	0.00			0.00	0.07	-0.03	0.01
92(CORC) FRPR	0.11	1.05	-0.10	-0.02			0.01	0.07	-0.03	0.02

Table 125

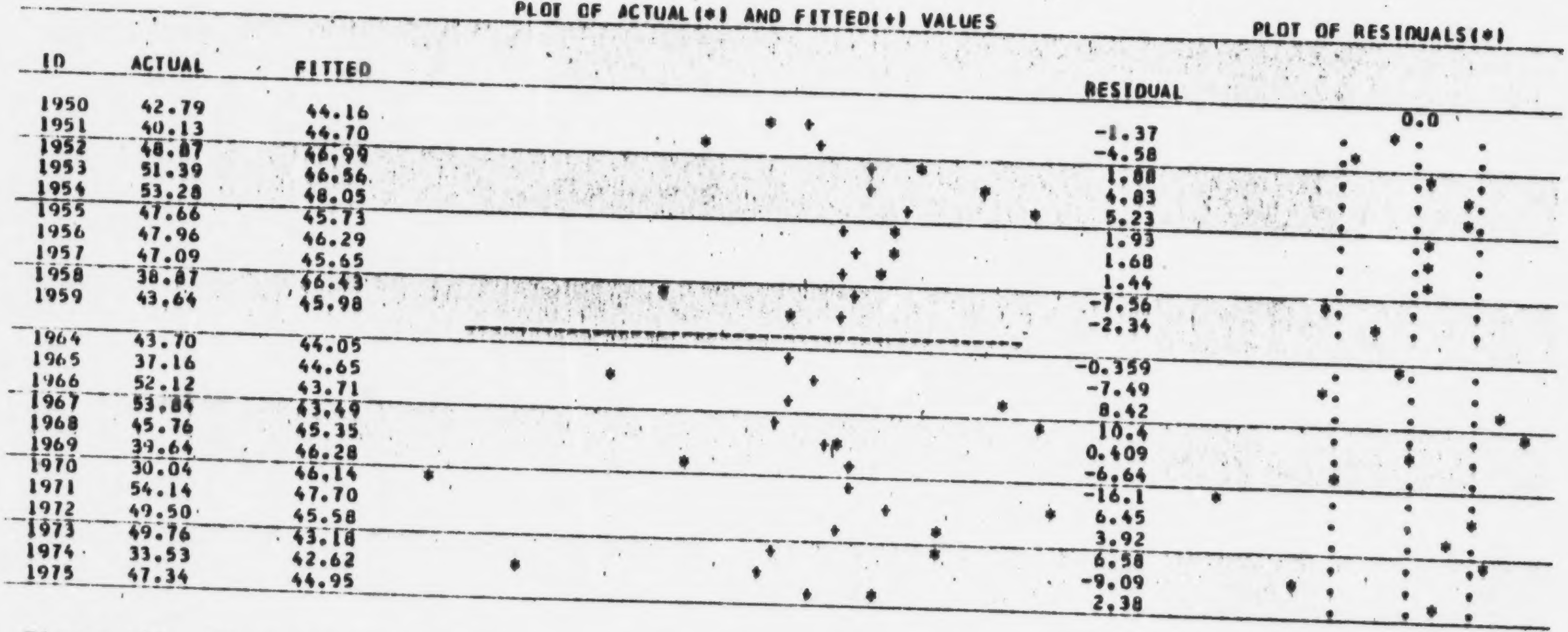
Pairwise Correlation Matrix for ST, PMECH, AP, and MACT: Eastern Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1975)

	ST	PMECH	AP	MACT
ST	1.0001	0.89994	0.56158	0.53725
PMECH	0.89994	1.0000	0.58724	0.65988
AP	0.56158	0.58724	1.0000	0.089581
MACT	0.53725	0.65988	0.089581	1.0000

Table 126

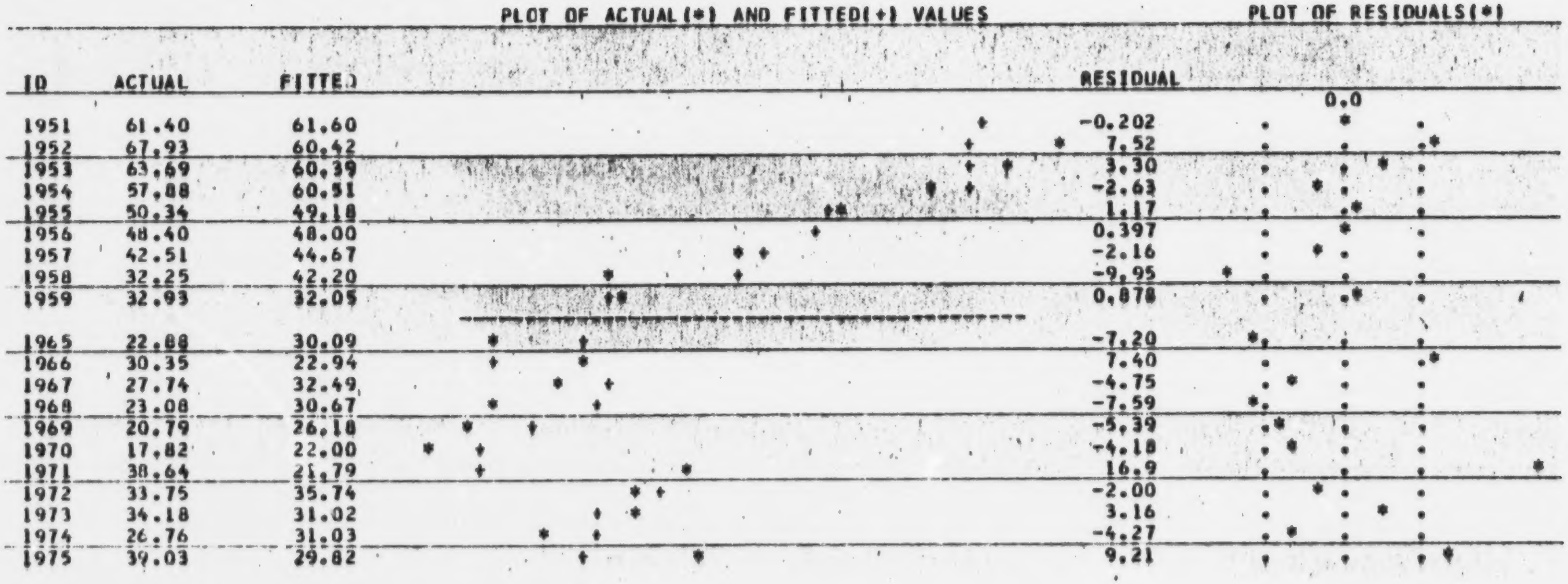
Pairwise Correlation Matrix for ST, PMECH, AEMPL, and MACT: Eastern Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1975)

	ST	PMECH	AEMPL	MACT
ST	1.0001	0.89994	−0.78495	0.53725
PMECH	0.89994	1.0000	−0.63538	0.65988
AEMPL	−0.78495	−0.63538	1.0000	−0.10572
MACT	0.53725	0.65988	−0.10572	1.0000



ID	ACTUAL	FITTED	RESIDUAL
1950	42.79	44.16	-1.37
1951	40.13	44.70	-4.58
1952	48.87	46.99	1.88
1953	51.39	46.56	4.83
1954	53.28	48.05	5.23
1955	47.66	45.73	1.93
1956	47.96	46.29	1.68
1957	47.09	45.65	1.44
1958	38.87	46.43	-7.56
1959	43.64	45.98	-2.34
1964	43.70	44.05	-0.359
1965	37.16	44.65	-7.49
1966	52.12	43.71	8.42
1967	53.84	43.49	10.4
1968	45.76	45.35	0.409
1969	39.64	46.28	-6.64
1970	30.04	46.14	-16.1
1971	54.14	47.70	6.45
1972	49.50	45.58	3.92
1973	49.76	43.18	6.58
1974	33.53	42.62	-9.09
1975	47.34	44.95	2.38

Figure 199. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1950 Through 1959 and 1964 Through 1975: Eastern Kentucky (OLS)



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ID      ACTUAL      FITTE.)      RESIDUAL

1951    61.40       61.60        -0.202
1952    67.93       60.42         7.52
1953    63.69       60.39         3.30
1954    57.88       60.51        -2.63
1955    50.34       49.18         1.17
1956    48.40       48.00         0.397
1957    42.51       44.67        -2.16
1958    32.25       42.20        -9.95
1959    32.93       32.05         0.878

1965    22.88       30.09        -7.20
1966    30.35       22.94         7.40
1967    27.74       32.49        -4.75
1968    23.08       30.67        -7.59
1969    20.79       26.18        -5.39
1970    17.82       22.00        -4.18
1971    38.64       21.79        16.9
1972    33.75       35.74        -2.00
1973    34.18       31.02         3.16
1974    26.76       31.03        -4.27
1975    39.03       29.82         9.21
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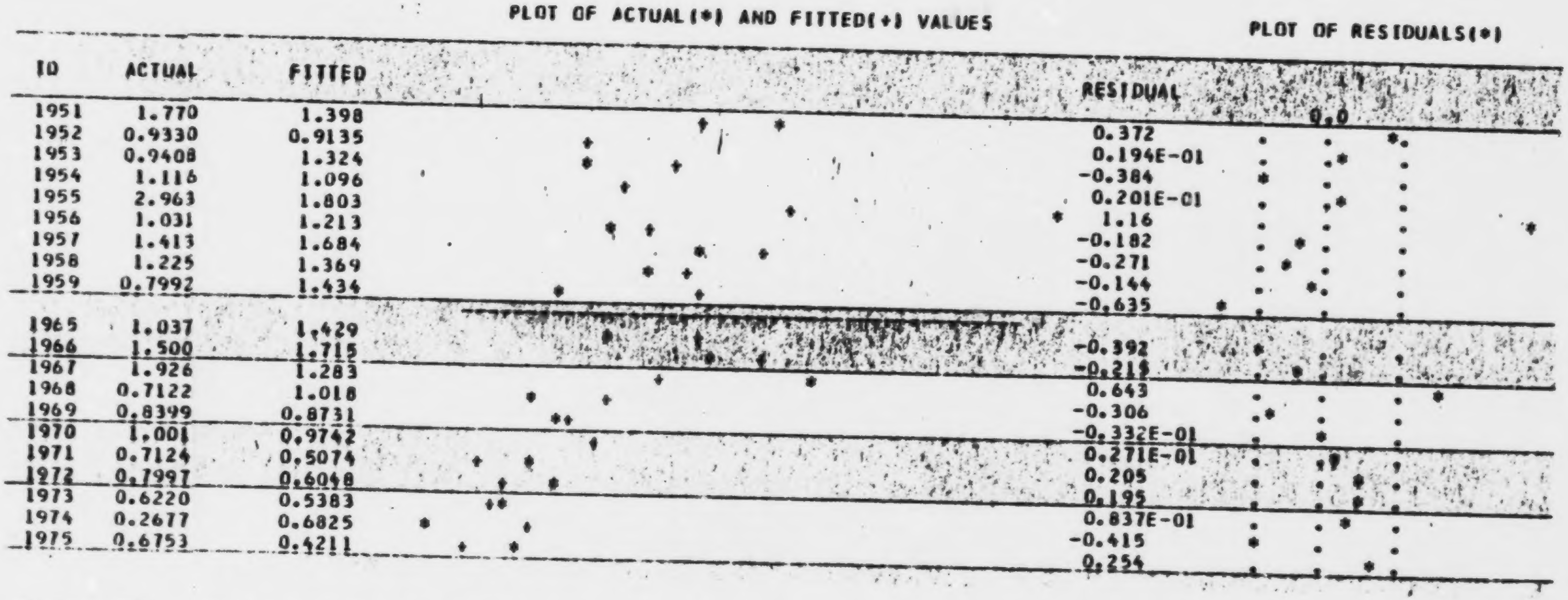
Figure 200. Plots for Nonfatal Injury Rate Per Million Tons, 1950 Through 1959 and 1964 Through 1975: Eastern Kentucky (CORC)

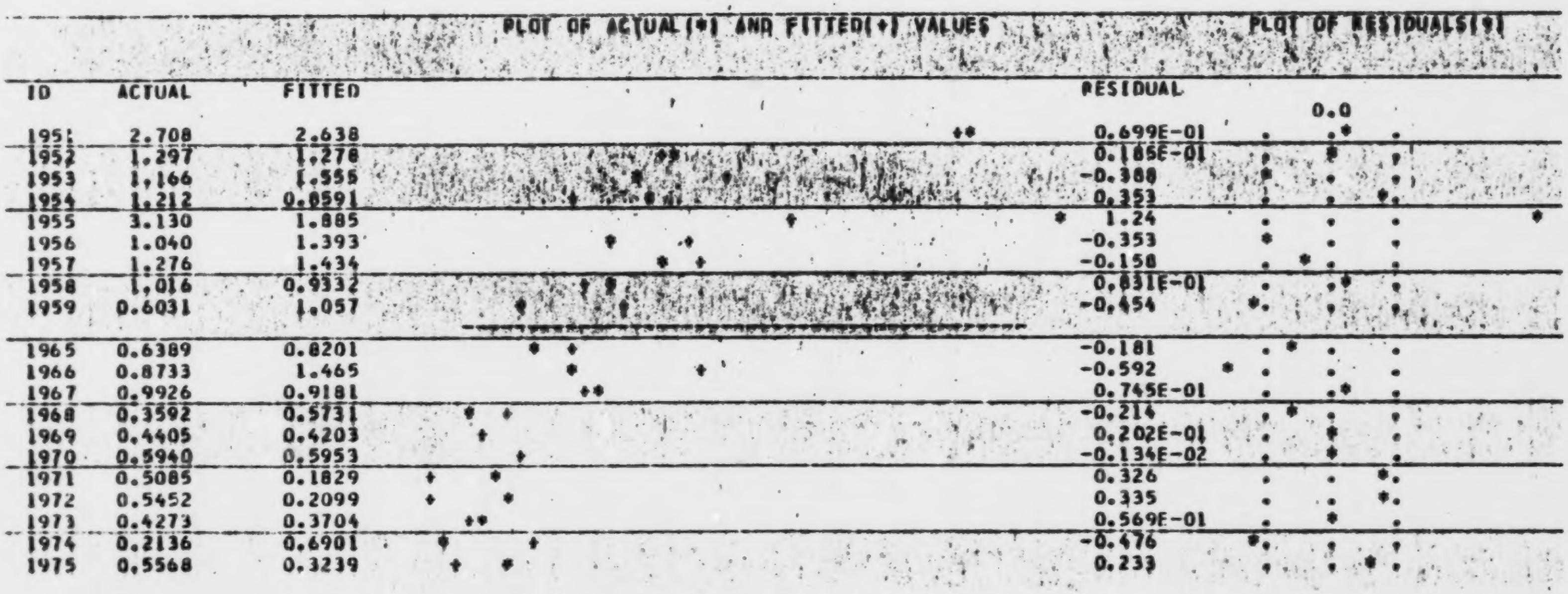


```
                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES        PLOT OF RESIDUALS(*)

ID     ACTUAL     FITTED                                RESIDUAL        0.0
1951   1.770      1.398                                 0.372
1952   0.9330     0.9135                                0.194E-01
1953   0.9408     1.324                                 -0.384
1954   1.116      1.096                                 0.201E-01
1955   2.963      1.803                                 1.16
1956   1.031      1.213                                 -0.182
1957   1.413      1.684                                 -0.271
1958   1.225      1.369                                 -0.144
1959   0.7992     1.434                                 -0.635

1965   1.037      1.429                                 -0.392
1966   1.500      1.715                                 -0.215
1967   1.926      1.283                                 0.643
1968   0.7122     1.018                                 -0.306
1969   0.8399     0.8731                                -0.332E-01
1970   1.001      0.9742                                0.271E-01
1971   0.7124     0.5074                                0.205
1972   0.7997     0.6048                                0.195
1973   0.6220     0.5383                                0.837E-01
1974   0.2677     0.6825                                -0.415
1975   0.6753     0.4211                                0.254
```

Figure 201. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1959 and 1964 Through 1975: Eastern Kentucky (CORC)



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                                  PLOT OF ACTUAL(*) AND FITTED(+) VALUES            PLOT OF RESIDUALS(*)
ID     ACTUAL       FITTED                                                  RESIDUAL
                                                                                          0.0
1951   2.708        2.638                                                   0.699E-01
1952   1.297        1.278                                                   0.185E-01
1953   1.166        1.555                                                  -0.388
1954   1.212        0.8591                                                  0.353
1955   3.130        1.885                                                   1.24
1956   1.040        1.393                                                  -0.353
1957   1.276        1.434                                                  -0.158
1958   1.016        0.9332                                                  0.831E-01
1959   0.6031       1.057                                                  -0.454

1965   0.6389       0.8201                                                 -0.181
1966   0.8733       1.465                                                  -0.592
1967   0.9926       0.9181                                                  0.745E-01
1968   0.3592       0.5731                                                 -0.214
1969   0.4405       0.4203                                                  0.202E-01
1970   0.5940       0.5953                                                 -0.134E-02
1971   0.5085       0.1829                                                  0.326
1972   0.5452       0.2099                                                  0.335
1973   0.4273       0.3704                                                  0.569E-01
1974   0.2136       0.6901                                                 -0.476
1975   0.5568       0.3239                                                  0.233
```

Figure 202. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1959 and 1964 Through 1975: Eastern Kentucky (CORC)

unexpectedly positive and significant. Coefficients of PMECH are positive and not significant for NFRMH and NFRPR, but they are negative, as expected, and significant for FRMH and FRPR. The mine-size variables have coefficients that are negative and not significant for the nonfatal injury rates; for FRMH, AP is positive but not significant, and for FRPR, AEMPL is positive and significant. None of the coefficients of MACT are significant, but they are negative, as expected, in all regressions that do not have autocorrelation.

Results of Regressions for 1964 Through 1975 for Underground Rail-Connected and Truck Mines

As for the analysis of productivity, data on all mines are available only from 1964 through 1975 (Table 127). The results for rail-connected mines alone reflect larger average mine size than all mines, and also somewhat greater ST values. The regression results for all mines are summarized in Tables 128 and 129. The correlation matrices are presented in Tables 130 and 131. These results will be compared to those for rail-connected mines in the summary part of this section.

Results of Regressions for Underground Rail-Connected Mines Using Data Through 1969 and Predictions of Productivity

In this section, results of regressions on data through 1969 are presented, and predictions of injury rates are made assuming there is no CMHSA. Trends of the independent variables suggest they are not affected by the Mine Act. Results of regressions are presented in Tables 132 and 133; correlation matrices are presented in Tables 134 and 135. Pairwise correlations are rather high, with the greatest being between ST and PMECH (0.87) and between ST and AEMPL (-0.87). Equations

Table 127

Data for Eastern Kentucky Injury Model: Underground Rail-Connected and Truck Mines

Year	Number of Nonfatal Injuries NFTL	Nonfatal Injury Rate Per Million Man-Hours NFRMH	Nonfatal Injury Rate Per Million Tons NFRPR	Total Number of Fatal Injuries FTL	Number of Disaster Fatalities DFTL	Fatal Injury Rate Per Million Man-Hours FRMH	Fatal Injury Rate Excluding Disaster Fatalities Per Million Man-Hours FRMHND
1964	1173	44.6718	31.3356	36	0.0	1.37100	1.37100
1965	1010	39.1281	26.8692	33	0.0	1.27844	1.27844
1966	1083	43.0611	26.1152	28	0.0	1.11331	1.11331
1967	1045	43.7195	23.9884	34	0.0	1.42245	1.42245
1968	954	42.2920	22.0807	33	0.0	1.46293	1.46293
1969	791	35.6372	18.0447	23	0.0	1.03623	1.03623
1970	673	28.6554	15.3995	70	38	2.98050	1.36252
1971	1054	46.3315	28.6964	29	0.0	1.27478	1.27478
1972	1046	46.6117	27.6208	23	0.0	1.02492	1.02492
1973	1086	45.9798	26.5455	16	0.0	0.677418	0.677418
1974	1052	39.9550	25.5447	18	0.0	0.683641	0.683641
1975	1202	44.2944	29.2408	19	0.0	0.700161	0.600161

Table 127 (Continued)

Year	Fatal Injury Rate Per Million Tons FRPR	Fatal Injury Rate Excluding Disaster Fatalities Per Million Tons FRPRND	Total Production TPROD X 10^{-6} (millions of short tons)	Number of Man-Days Worked MNDY X 10^{-6} (millions of man-days)	Weighted-Average Seam Thickness ST (inches)	Percent of Coal Loaded Mechanically PMECH	Weighted-Average Employment AEMPL	Average Production AP X 10^6 (short tons)	Number of Inspections Per Mine Under CMHSA MACT
1964	0.961706	0.961706	37.4335	3.28228	42.25	71.48	5	21208.8	0.0
1965	0.877904	0.877904	37.5895	3.22658	42.12	76.96	6	23671.0	0.0
1966	0.675187	0.675187	41.4700	3.14379	43.15	81.36	6	28153.4	0.0
1967	0.780484	0.780484	43.5627	2.98780	43.16	85.64	6	34328.4	0.0
1968	0.763797	0.763797	43.2052	2.81969	43.72	90.05	7	37832.9	0.0
1969	0.524689	0.524689	43.8355	2.77449	44.24	96.04	7	42230.7	0.0
1970	1.60173	0.732220	43.7027	2.93575	44.61	91.89	8	40996.9	5.15924
1971	0.789561	0.789561	36.7293	2.84363	44.47	95.06	8	39923.1	10.4678
1972	0.607341	0.607341	37.8700	2.80509	44.85	97.14	11	52306.6	29.2330
1973	0.391094	0.391094	40.9108	2.95239	44.38	98.39	13	67398.4	42.6833
1974	0.437077	0.437077	41.1826	3.29120	44.61	99.44	11	51802.1	52.0947
1975	0.462209	0.462209	41.1069	3.39208	43.92	99.61	10	44925.6	39.1479

Table 128

Results of Regressions for Injury Model: Eastern Kentucky Underground Rail-Connected and Truck Mines (1964 Through 1975)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-correlation (Durbin-Watson Statistic)	F-Statistic
93(OLS) NFRMI	179.089 (182.497)	-3.278 (5.070)	-0.012 (0.574)	147.064 (339.803)		0.087 (0.156)	0.21	5.85	None(2.11)	$0.46^{‡}_{(4,7)}$
94(OLS) NFRPR	135.224 (128.511)	-2.146 (3.640)	-0.202 (0.387)		-0.117 (1.616)	0.206 (0.172)	0.50	4.09	None(2.16)	$1.78^{‡}_{(4,7)}$
95(OLS) FRMI	-29.305 (16.113)	0.840 (0.448)	-0.063 (0.051)	-8.373 (30.001)		-0.014 (0.014)	0.55	0.52	None(2.90)	$2.13^{‡}_{(4,7)}$
96(OLS) FRMIND	-4.199 (4.879	0.159 (0.136)	-0.015 (0.015)	-2.403 (9.085)		-0.011 (0.004) ###	0.82	0.16	None(2.67)	$8.03_{(4,7)}$
97(OLS) FRPR	-14.048 (8.736)	0.433 (0.247)	-0.044 (0.026) #		-0.012 (0.110)	-0.004 (0.012)	0.54	0.28	None(2.63)	$2.05^{‡}_{(4,7)}$
98(OLS) FRPRND	-1.296 (3.188)	0.085 (0.090)	-0.018 (0.010) #		-0.016 (0.040)	-0.002 (0.004)	0.80	0.10	None(2.34)	$7.19_{(4,7)}$

‡The equation is not significant at the 95.0 percent confidence level or greater.

Significance Levels: # Significant at the 90.0 percent confidence level (one-tail test)
Significant at the 97.5 percent confidence level (one-tail test)

Table 129

Ninety-Five Percent Confidence Intervals for Coefficients in Eastern Kentucky Regressions of Injury Model: Underground Rail-Connected and Truck Mines (1964 Through 1975)

Equation Dependent Variable	ST		PMECH		AP		AEMPL		MACT	
93(OLS) NFRMH	-15.27	8.71	-1.37	1.35	-656.57	950.70			-0.28	0.46
94(OLS) NFRPR	-10.75	6.46	-1.12	0.71			-3.94	3.70	-0.20	0.61
95(OLS) FRMH	-0.22	1.90	-0.18	0.06	-79.33	62.58			-0.05	0.02
96(OLS) FRMHND	-0.16	0.48	-0.05	0.02	-23.89	19.08			-0.02	-0.00
97(OLS) FRPR	-0.15	1.02	-0.11	0.02			-0.27	0.25	-0.03	0.02
98(OLS) FRPRND	-0.13	0.30	-0.04	0.01			-0.11	0.08	-0.01	0.01

Table 130

Pairwise Correlation Matrix for ST, PMECH, AP, and MACT: Eastern Kentucky Underground Rail-Connected and Truck Mines (1964 Through 1975)

	ST	PMECH	AP	MACT
ST	1.0001	0.91393	0.81844	0.56530
PMECH	0.91393	1.0000	0.87357	0.70160
AP	0.81844	0.87357	1.0000	0.79250
MACT	0.56530	0.70160	0.79250	1.0000

Table 131

Pairwise Correlation Matrix for ST, PMECH, AEMPL, and MACT: Eastern Kentucky Underground Rail-Connected and Truck Mines (1964 Through 1975)

	ST	PMECH	AEMPL	MACT
ST	1.0001	0.91393	0.73859	0.56530
PMECH	0.91393	1.0000	0.81349	0.70160
AEMPL	0.73859	0.81349	1.0000	0.91423
MACT	0.56530	0.70160	0.91423	1.0000

Table 132

Results of Regressions for Injury Model: Eastern Kentucky Underground Rail-Connected Mines
(1950 Through 1959 and 1964 Through 1969)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	R^2	S	Auto-correlation (Durbin-Watson Statistic)	F-Statistic
99 (OLS) NFRMH	14.971 (98.314)	0.643 (2.305)	0.049 (0.313)	-22.344 (41.444)		0.04	5.81	None (1.42)	$0.16^{\dagger}$ (3,12)
100 (CORC) NFRMH	-30.307 (112.795)	1.861 (2.591)	-0.210 (0.420)	- 2.918 (58.466)		0.11	6.00	None (2.02)	$0.42^{\dagger}$ (3,10)
101 (OLS) NFRAR	373.909 (235.283)	-5.972 (4.849)	-0.540 (0.421)		0.084 (0.300)	0.76	9.47	+ (0.87)	12.95 (3,12)
102 (CORC) NFRPR	- 11.709 (107.718)	0.585 (1.836)	0.078 (0.411)		-0.258 (0.171)	0.93	4.99	None (2.05)	44.53 (3,10)
103 (OLS) FRMH	- 11.457 (10.414)	0.309 (0.244)	-0.041 (0.033)	1.325 (4.390)		0.13	0.62	None (2.42)	$0.59^{\dagger}$ (3,12)
104 (CORC) FRMH	- 21.634 (9.764)	0.576 (0.230) **	-0.093 (0.034) ###	5.296 (4.129)		0.44	0.51	None (2.02)	$2.59^{\dagger}$ (3,10)
105 (OLS) FRPR	- 24.023 (14.882)	0.531 (0.307)	-0.050 (0.027)	0.039 (0.019)		0.53	0.60	None (1.83)	4.42 (3,12)

Table 133

Ninety-Five Percent Confidence Intervals for Coefficients in Eastern Kentucky Regressions of Injury Model: Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1969)

Equation Dependent Variable	ST		PMECH		AP		AEMPL	
99 (OLS) NFRMH	- 4.38	5.67	-0.63	0.73	-112.65	67.96		
100 (CORC) NFRMH	- 3.91	7.63	-1.15	0.73	-133.18	127.34		
101 (OLS) NFRPR	-16.54	4.59	-2.37	1.29			-0.57	0.74
102 (CORC) NFRPR	- 3.51	4.68	-0.84	0.99			-0.64	0.12
103 (OLS) FRMH	- 0.22	0.84	-0.11	0.03	- 8.24	10.89		
104 (CORC) FRMH	0.06	1.09	-0.17	-0.02	- 3.90	14.50		
105 (OLS) FRPR	- 0.14	1.20	-0.11	0.01			-0.00	0.08

Table 134

Pairwise Correlation Matrix for ST, PMECH, and AP: Eastern Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1969)

	ST	PMECH	AP
ST	1.0001	0.87403	0.61544
PMECH	0.87403	1.0000	0.75368
AP	0.61544	0.75368	1.0000

Table 135

Pairwise Correlation Matrix for ST, PMECH, and AEMPL: Eastern Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1969)

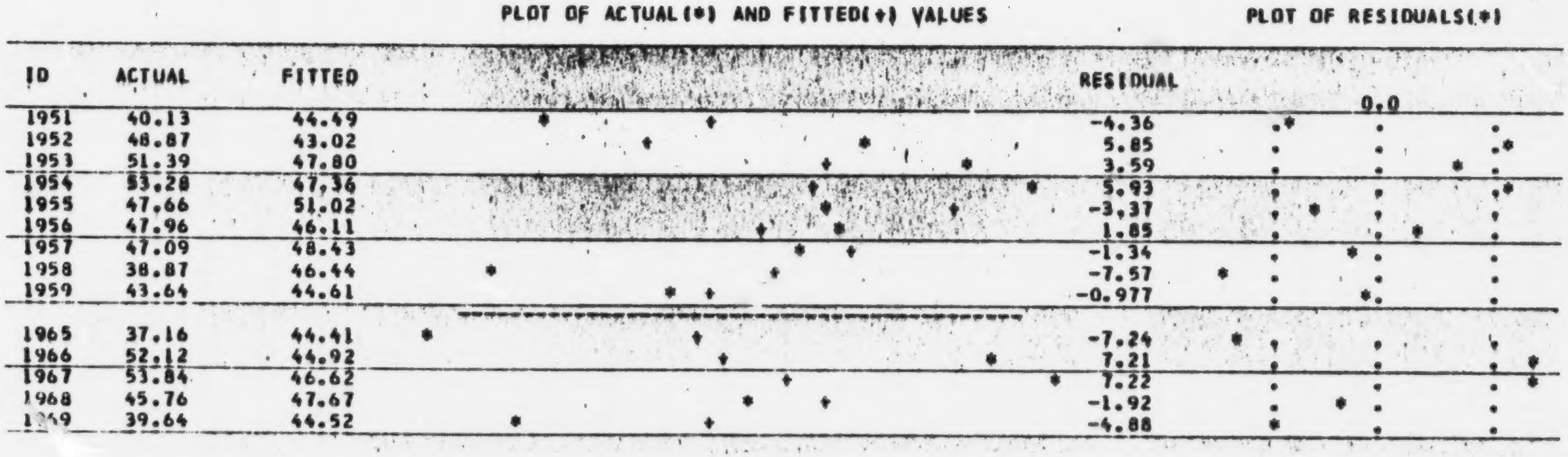
	ST	PMECH	AEMPL
ST	1.0001	0.87403	-0.86657
PMECH	0.87403	1.0000	-0.75988
AEMPL	-0.86657	-0.75988	1.0000

for NFRMH and FRMH are not significant, and R^2 is only 0.11 for the former. Results for the injury rates per million tons are better, with 93.0 and 53.0 percent of the variance explained for NFRPR and FRPR, respectively. Appropriate plots are shown in Figures 203 through 206. There is no evidence of heteroskedasticity. Coefficients of ST are positive and not significant; those of PMECH are negative for all regressions except NFRPR, but significant only for FRMH and FRPR. Coefficients of mine-size variables are negative and not significant for nonfatal injury rates, and they are positive for fatal injury rates and significant for FRPR.

Predictions of injury rates using these results are presented in Table 136. Except in 1970 and 1974, actual NFRMH are greater than predicted; however, the only significant difference is in 1970. Actual NFRPR are all greater than predicted, with statistically significant differences in all years except 1970 and 1974. In all years except 1974, actual FRMH are greater than predicted, but none of these differences are statistically significant. For FRPR, predicted rates are greater than actual in all years except 1971 and 1972, but these differences are not significant.

Data for all mines cannot be used for predictions since there are only six observations.

Predictions based on results of the regressions using data through 1975 are presented in Tables 137 and 138. For nonfatal injury rates, actual rates are significantly less than predicted in 1970; however, in 1971, actual rates are greater than predicted. In all other years,



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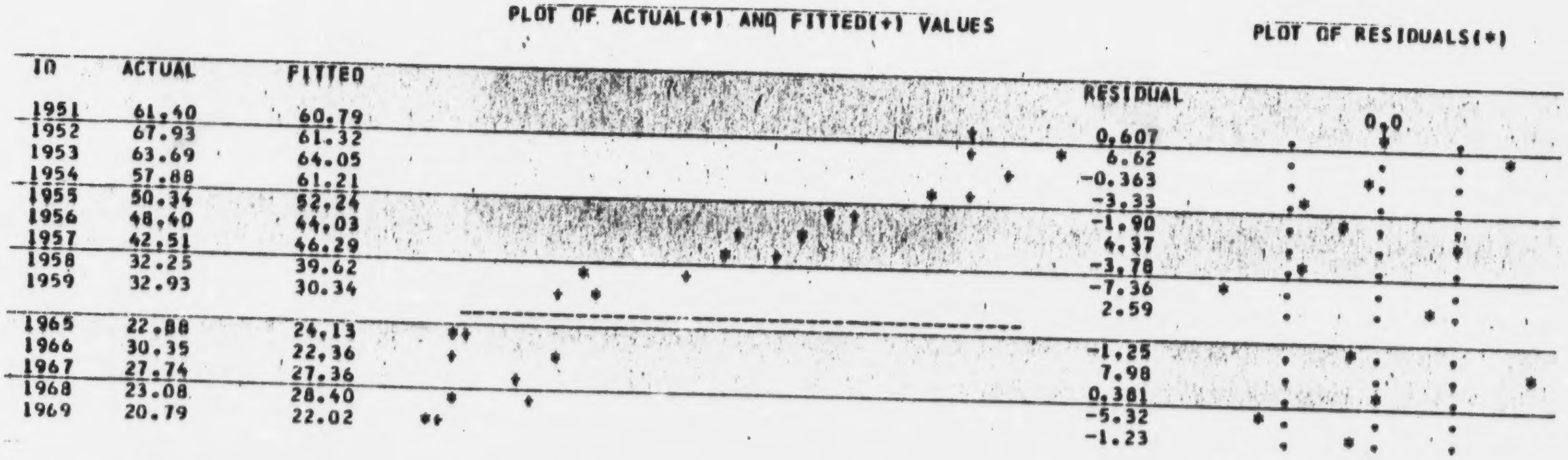
ID      ACTUAL     FITTED      RESIDUAL
1951    40.13      44.49       -4.36
1952    48.87      43.02        5.85
1953    51.39      47.80        3.59
1954    53.28      47.36        5.93
1955    47.66      51.02       -3.37
1956    47.96      46.11        1.85
1957    47.09      48.43       -1.34
1958    38.87      46.44       -7.57
1959    43.64      44.61       -0.977

1965    37.16      44.41       -7.24
1966    52.12      44.92        7.21
1967    53.84      46.62        7.22
1968    45.76      47.67       -1.92
1969    39.64      44.52       -4.88
```

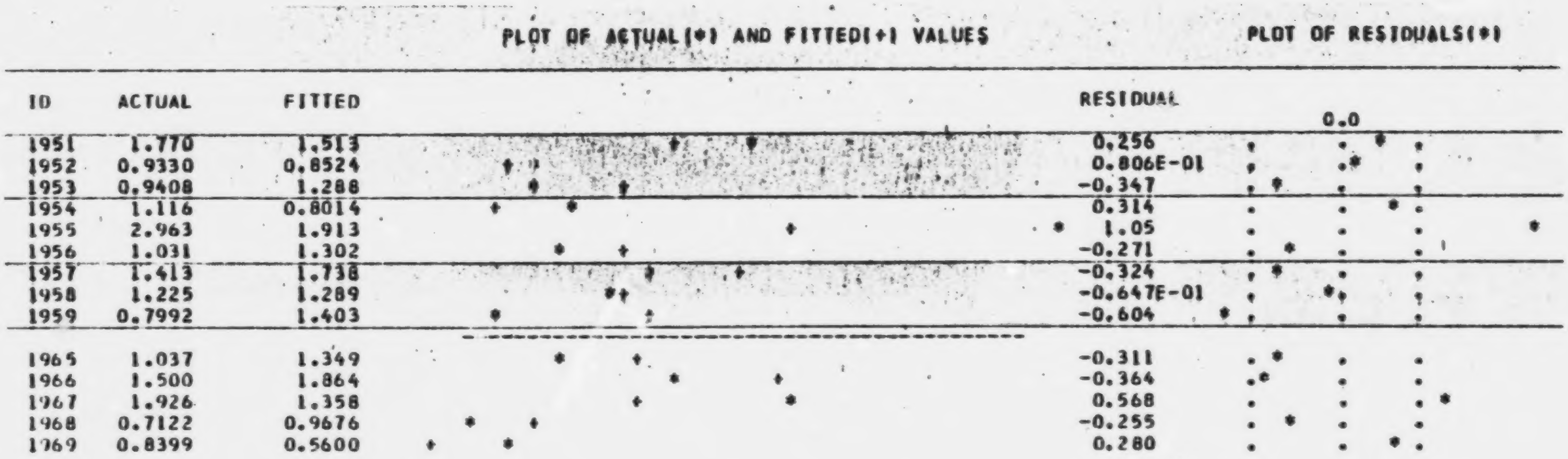
Figure 203. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1950 Through 1959 and 1964 Through 1969: Eastern Kentucky (CORC)



```
                         PLOT OF ACTUAL(*) AND FITTED(+) VALUES                  PLOT OF RESIDUALS(*)
ID     ACTUAL      FITTED                                           RESIDUAL
                                                                                         0.0
1951   61.40       60.79                                            0.607
1952   67.93       61.32                                            6.62
1953   63.69       64.05                                           -0.363
1954   57.88       61.21                                           -3.33
1955   50.34       52.24                                           -1.90
1956   48.40       44.03                                            4.37
1957   42.51       46.29                                           -3.78
1958   32.25       39.62                                           -7.36
1959   32.93       30.34                                            2.59

1965   22.88       24.13                                           -1.25
1966   30.35       22.36                                            7.98
1967   27.74       27.36                                            0.381
1968   23.08       28.40                                           -5.32
1969   20.79       22.02                                           -1.23
```

Figure 204. Plots for Nonfatal Injury Rate Per Million Tons, 1950 Through 1959 and 1964 Through 1969: Eastern Kentucky (CORC)

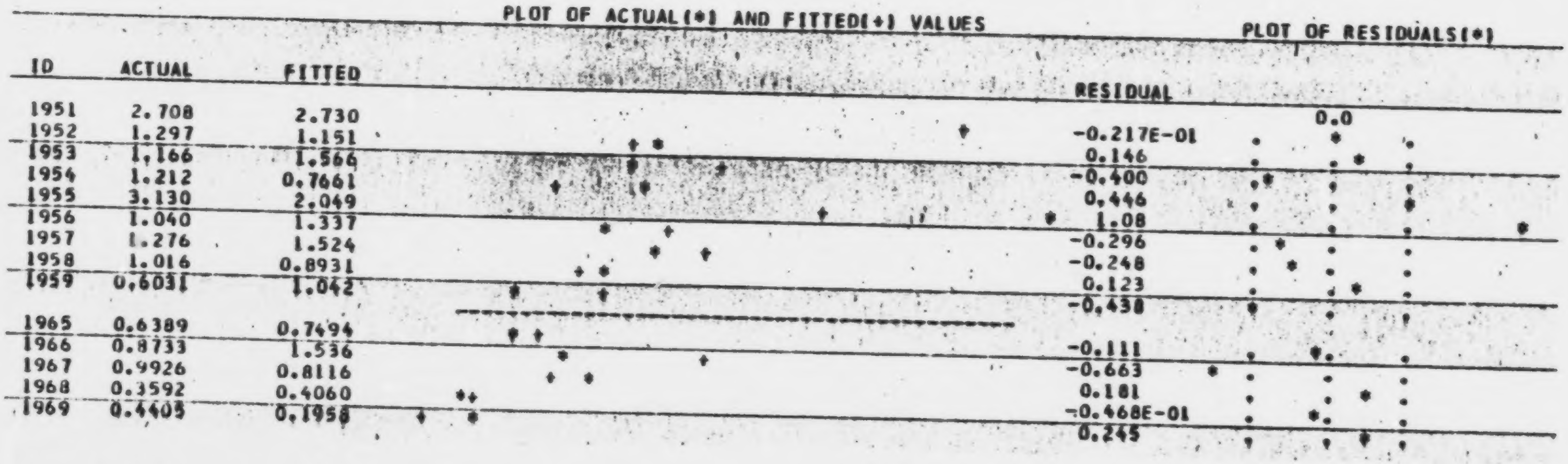


```
                                   PLOT OF ACTUAL(*) AND FITTED(+) VALUES               PLOT OF RESIDUALS(*)

ID     ACTUAL      FITTED                                                RESIDUAL
                                                                                          0.0
1951   1.770       1.513                                                 0.256
1952   0.9330      0.8524                                                0.806E-01
1953   0.9408      1.288                                                -0.347
1954   1.116       0.8014                                                0.314
1955   2.963       1.913                                                 1.05
1956   1.031       1.302                                                -0.271
1957   1.413       1.738                                                -0.324
1958   1.225       1.289                                                -0.647E-01
1959   0.7992      1.403                                                -0.604

1965   1.037       1.349                                                -0.311
1966   1.500       1.864                                                -0.364
1967   1.926       1.358                                                 0.568
1968   0.7122      0.9676                                               -0.255
1969   0.8399      0.5600                                                0.280
```

Figure 205. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1959 and 1964 Through 1969: Eastern Kentucky (CORC)



ID	ACTUAL	FITTED	RESIDUAL
1951	2.708	2.730	
1952	1.297	1.151	-0.217E-01
1953	1.166	1.566	0.146
1954	1.212	0.7661	-0.400
1955	3.130	2.049	0.446
1956	1.040	1.337	1.08
1957	1.276	1.524	-0.296
1958	1.016	0.8931	-0.248
1959	0.6031	1.042	0.123
			-0.438
1965	0.6389	0.7494	
1966	0.8733	1.536	-0.111
1967	0.9926	0.8116	-0.663
1968	0.3592	0.4060	0.181
1969	0.4405	0.1958	-0.468E-01
			0.245

Figure 206. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1959 and 1964 Through 1969: Eastern Kentucky (CORC)

Table 136

Comparison of Predicted Levels of Injury Rates Based on Multiple Regressions With Actual Injury Rates: Eastern Kentucky Underground Rail-Connected Mines

Injury Rate		Year					
		1970	1971	1972	1973	1974	1975
NFRMH (CORC)	Predicted	45.20	43.80	44.75	44.27	45.38	43.90
		(±15.15)	(±17.69)	(±17.69)	(±16.98)	(±17.69)	(±20.96)
	Actual	30.03	54.14	49.50	49.76	33.53	47.34
NFRPR (CORC)	Predicted	12.68	12.04	13.69	11.41	11.38	10.68
		(±15.74)	(±18.43)	(±17.73)	(±20.63)	(±23.51)	(±22.15)
	Actual	17.82	38.64	33.75	34.18	26.76	39.03
FRMH (CORC)	Predicted	0.69	-0.03	0.16	0.20	0.34	-0.13
		(± 1.37)	(± 1.67)	(± 1.67)	(± 1.58)	(± 1.67)	(± 1.79)
	Actual	0.59	0.51	0.55	0.43	0.21	0.56

Table 137

Effect of MACT on Nonfatal Injury Rates In Underground Rail-Connected Mines: Eastern Kentucky

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate From Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Nonfatal Injuries Per Million Man-Hours								
NFRMH	1969	-0.424	-0.112	0.200	0				46.28				39.64	
	1970				5.15924	- 1.03	0.58	2.19	46.14	45.11	46.72	48.33	30.04	1.2
	1971				10.4678	2.09	1.7	4.44	47.70	45.61	48.87	52.14	54.14	2.4
	1972				29.2330	- 5.85	3.27	12.39	45.58	39.73	48.85	57.97	49.50	6.7
	1973				42.6833	- 8.54	4.78	18.10	43.18	34.64	47.96	61.28	49.76	10.0
	1974				52.0947	-10.42	5.83	22.09	42.62	32.20	48.45	64.71	33.53	12.0
	1975				39.1479	- 7.83	4.38	16.60	44.95	37.12	49.33	61.55	47.34	8.9
						Nonfatal Injuries Per Million Tons								
NFRPR	1969	-0.670	-0.109	0.451	0				26.18				20.79	
	1970				5.15924	- 2.33	0.56	3.46	22.00	19.67	22.56	25.46	17.82	2.5
	1971				10.4678	- 4.72	1.14	7.01	21.79	17.07	22.93	28.80	38.64	5.0
	1972				29.2330	-13.18	2.19	19.59	25.74	22.56	38.93	55.33	33.75	8.2
	1973				42.6833	-19.25	4.65	28.60	31.02	11.77	35.67	59.62	34.18	13.0
	1974				52.0947	-23.49	5.68	34.90	31.03	7.54	36.71	65.93	26.76	15.5
	1975				39.1479	-17.66	4.27	26.26	29.82	12.16	34.09	56.05	39.03	12.5

Table 138

Effect of MACT on Fatal Injury Rates In Underground Rail-Connected Mines: Eastern Kentucky

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Fatal Injuries Per Million Man-Hours								
FRMH	1969	-0.024	-0.003	0.017	0				0.87				0.84	
	1970				5.15924	-0.09	0.12	0.97	0.97	0.88	0.99	1.09	1.00	2.0
	1971				10.4678	-0.18	0.03	0.25	0.51	0.33	0.54	0.76	0.71	5.6
	1972				29.2330	-0.50	0.09	0.70	0.60	0.10	0.69	1.30	0.80	13.0
	1973				42.6833	-0.73	0.13	1.02	0.54	<0	1.15	1.56	0.62	53.0
	1974				52.0947	-0.89	0.16	1.25	0.68	<0	0.84	1.93	0.27	19.0
	1975				39.1479	-0.67	0.12	0.94	0.42	<0	0.54	1.36	0.68	22.2
						Fatal Injuries Per Million Tons								
FRPR	1969	-0.030	-0.007	0.016	0				0.42				0.44	
	1970				5.15924	-0.08	0.04	0.15	0.60	0.52	0.64	0.75	0.59	6.3
	1971				10.4678	-0.17	0.07	0.31	0.18	0.01	0.25	0.49	0.51	28.0
	1972				29.2330	-0.47	0.20	0.88	0.21	0	0.41	1.09	0.55	48.8
	1973				42.6833	-0.68	0.30	1.28	0.37	0	0.67	1.65	0.43	44.8
	1974				52.0947	-0.83	0.36	1.56	0.69	0	1.05	2.25	0.21	34.3
	1975				39.1479	-0.63	0.27	1.17	0.32	0	0.59	1.49	0.56	45.8

actual rates fall within prediction intervals. For fatal injury rates, actual values fall within prediction intervals except for FRPR in 1971 for which the actual rate exceeds predicted. Tables 137 and 138 also show percentage decreases in injury rates based on predictions made by the model as compared to predicted rates after eliminating the effects of MACT. In 1975, the prediction of NFRMH is less than that predicted without MACT by 8.9 percent. The corresponding comparisons for the other injury rates are: Actual NFRPR is reduced by 12.5 percent, actual FRMH is reduced by 22.2 percent, and actual FRPR is reduced by 5.8 percent. This analysis is also presented for truck mines and rail-connected mines (Tables 139 and 140). In 1970, nonfatal rates are significantly less than predicted, but in 1971, actual rates are significantly greater than predicted. In all other years, actual nonfatal rates fall within prediction intervals but greater than the mean value. Since the coefficient of MACT is positive, predictions of nonfatal rates are less without MACT than with this variable; thus, the percentages in Column (7) are negative. The only case in which an actual fatal rate is significantly less than predicted without MACT is for FRMH in 1971. In almost all other cases, actual values fall within prediction intervals but are less than the mean. The results suggest the following: (1) MACT has greater negative influence on FRMH in truck mines than in rail mines, and (2) MACT has greater negative influence on FRPR, NFRPR, and NFRMH in rail mines than in truck mines.

Summary

The relationships of the independent variables to the injury rates for rail-connected mines may be summarized as follows. For NFRMH: (1) weighted-average seam thickness is negatively related but not significant;

Table 139

Effect of MACT on Nonfatal Injury Rates in Underground Rail-Connected and Truck Mines: Eastern Kentucky

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Nonfatal Injuries Per Million Man-Hours								
NFRMH	1969	-0.282	0.087	0.456	0				39.13				35.64	
	1970				5.15924	- 2.35	- 0.45	1.45	38.23	35.88	37.78	39.68	28.66	- 1.2
	1971				10.4678	- 4.77	- 0.91	2.95	38.95	34.18	38.04	41.90	46.33	- 2.4
	1972				29.2330	-13.33	- 2.54	8.24	41.13	27.80	38.59	49.37	46.61	- 6.6
	1973				42.6833	-19.46	- 3.71	12.04	46.04	26.58	42.33	58.08	45.98	- 8.8
	1974				52.0947	-23.76	- 4.53	14.69	43.79	20.03	39.26	58.48	39.96	-11.5
	1975				39.1479	-17.85	- 3.41	11.04	43.92	26.07	40.51	54.96	44.29	- 8.4
						Nonfatal Injuries Per Million Tons								
NFRPK	1969	-0.201	0.206	0.613	0				20.06				18.04	
	1970				5.15924	- 3.16	- 1.06	1.04	21.05	17.89	19.99	22.09	15.40	- 5.3
	1971				10.4678	- 6.42	- 2.16	2.10	21.80	15.38	19.64	23.90	28.70	-11.0
	1972				29.2330	-17.92	- 6.02	5.88	24.07	6.15	18.05	29.95	27.62	-33.4
	1973				42.6833	-26.16	- 8.79	8.58	27.36	1.2	18.57	35.94	26.55	-47.3
	1974				52.0947	-31.93	-10.73	10.47	28.83	< 0	18.10	39.30	25.54	-59.3
	1975				39.1479	-24.00	- 8.06	7.87	27.73	3.73	19.67	35.60	29.24	-41.0

Table 140

Effect of MACT on Fatal Injury Rates for Underground Rail-Connected and Truck Mines: Eastern Kentucky

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate From Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Fatal Injuries Per Million Man-Hours								
FRMH	1969	-0.047	-0.014	0.019	0				1.46				1.04	
	1970				5.15924	-0.10	0.07	0.24	1.97	1.87	2.04	2.21	2.98	3.4
	1971				10.4678	-0.20	0.15	0.49	1.59	1.39	1.74	2.08	1.28	8.6
	1972				29.2330	-0.56	0.41	1.37	1.42	0.86	1.83	2.79	1.03	22.4
	1973				42.6833	-0.81	0.60	2.01	0.63	<0	1.23	2.64	0.68	48.8
	1974				52.0947	-0.99	0.73	2.45	0.76	<0	1.49	3.21	0.68	49.0
	1975				39.1479	-0.74	0.55	1.84	0.41	<0	0.96	2.25	0.70	57.3
						Fatal Injuries Excluding Disasters Per Million Man-Hours								
FRMHND	1969	-0.020	-0.011	0.002	0				1.26				1.04	
	1970				5.15924	-0.01	0.06	0.10	1.33	1.32	1.39	1.43	1.36	4.3
	1971				10.4678	-0.02	0.12	0.21	1.20	1.18	1.32	1.41	1.28	9.1
	1972				29.2330	-0.06	0.32	0.58	0.99	0.93	1.31	1.57	1.03	24.4
	1973				42.6833	-0.09	0.47	0.85	0.72	0.63	1.19	1.57	0.68	39.5
	1974				52.0947	-0.10	0.57	1.04	0.67	0.57	1.24	1.71	0.68	46.0
	1975				39.1479	-0.08	0.43	0.78	0.72	0.64	1.15	1.50	0.70	37.4

Table 140 (Continued)

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate From Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Fatal Injuries Per Million Tons								
FRPR	1969	-0.032	-0.004	0.024	0.				0.76				0.52	
	1970				5.15924	-0.12	0.02	0.17	1.07	0.95	1.09	1.24	1.60	1.8
	1971				10.4678	-0.25	0.04	0.33	0.84	0.59	0.88	1.17	0.79	4.5
	1972				29.2330	-0.70	0.12	0.94	0.79	0.09	0.91	1.73	0.61	13.2
	1973				42.6833	-1.02	0.17	1.37	0.45	0	0.62	1.82	0.39	27.4
	1974				52.0947	-1.25	0.21	1.67	0.49	0	0.70	2.16	0.44	30.0
	1975				39.1479	-0.94	0.16	1.25	0.25	0	0.41	1.50	0.46	39.0
						Fatal Injuries Excluding Disasters Per Million Tons								
FRPRND	1969	-0.011	-0.002	0.007	0				0.65				0.52	
	1970				5.15924	-0.04	0.01	0.06	0.73	0.69	0.74	0.79	0.73	1.4
	1971				10.4678	-0.07	0.02	0.12	0.65	0.58	0.67	0.77	0.79	3.0
	1972				29.2330	-0.20	0.06	0.32	0.56	0.36	0.62	0.88	0.61	9.7
	1973				42.6833	-0.30	0.09	0.47	0.45	0.15	0.54	0.92	0.39	16.7
	1974				52.0947	-0.36	0.10	0.57	0.46	0.10	0.56	1.03	0.44	17.9
	1975				39.1479	-0.27	0.08	0.43	0.44	0.17	0.52	0.87	0.46	15.4

(2) percent mechanically loaded is positively related and not significant; (3) average production is negatively related and not significant; and (4) the Mine-Act variable is negatively related but not significant. For NFRPR: (1) weighted-average seam thickness is negatively related but not significant; (2) percent mechanically loaded is positively related and not significant; (3) weighted-average employment is negatively related and not significant; and (4) the Mine-Act variable is negatively related but not significant. For FRMH: (1) weighted-average seam thickness is positively related and significant; (2) percent mechanically loaded is negatively related and significant; (3) average production is positively related and not significant; and (4) the Mine-Act variable is negatively related but not significant. For FRPR: (1) weighted-average seam thickness is positively related and significant; (2) percent mechanically loaded is negatively related and significant; (3) weighted-average employment is positively related and significant; and (4) the Mine-Act variable is negatively related but not significant.

The effects of each independent variable on the injury rates may be summarized as follows: (1) an increase in ST of one inch decreases NFRMH by 0.92, decreases NFRPR by 2.01, increases FRMH by 0.43, and increases FRPR by 0.58; (2) an increase in PMECH of one increases NFRMH by 0.21, increases NFRPR by 0.30, decreases FRMH by 0.06, and decreases FRPR by 0.06; (3) an increase in AP of one million tons decreases NFRMH by 33.36 and increases FRMH by 2.11; (4) an increase in AEMPL of ten, decreases NFRPR by 0.17 and increases FRPR by 0.04; and (5) an increase in the value of MACT by one decreases NFRMH by 0.11, decreases NFRPR by 0.11, decreases FRMH by 0.003, and decreases FRPR by 0.01.

The results for Eastern Kentucky suggest that the Mine Act had little negative influence on injury rates. Furthermore, a comparison of results for all mines with those for rail mines suggests that the Mine Act had, if anything, a greater negative effect on injury rates in rail-connected mines than in truck mines, with the possible exception of FRMH. Furthermore, the coefficient of MACT is significant (negative) only for FRMHND for all mines.

Western Kentucky

Data and Trends of Variables

Data for western Kentucky are shown in Table 141. Sources are discussed in the section on eastern Kentucky.

Trends over time of the accident rates are shown in Figures 207 through 212. Nonfatal injury rates per million man-hours (NFRMH) show an overall increasing rate prior to 1968 or 1969; in 1964 the rate is very high, then values decline somewhat thereafter (Figure 207). Nonfatal injury rates per million tons (NFRPR) have an overall declining trend prior to 1969; however, after 1965 the trend is more level (Figure 208). Fatal injury rates per million man-hours (FRMH) show an overall level to increasing trend from 1950 through 1968 (a disaster year), then show an overall declining trend (Figure 209). Fatal injury rates excluding disaster per million man-hours (FRMHND) have the same trend without the extreme value in 1968 (Figure 210). Fatal injury rates per million tons (FRPR) show an overall declining trend throughout the time period (Figure 211). Fatal injury rates excluding disaster per million tons (FRPRND) show the same trend, except for the lower rate in 1968 (Figure 212). Piecewise regressions were made with join points of 1969 to test the presence of a significant break in trend for each injury rate (Table 142). The results suggest a break in trend from increasing to decreasing rates for NFRMH and FRMH, neither of these equations are significant at the 95.0 percent confidence level.

Trends for weighted-average seam thickness and average production (Figure 98 and 100) are described in Chapter III. The trend of percent of coal loaded mechanically (Figure 197) is described in the section on eastern

Table 141

Data for Western Kentucky Injury Model: Underground Rail-Connected Mines

Year	Number of Nonfatal Injuries NFTL	Nonfatal Injury Rate Per Million Man-Hours NFRMH	Nonfatal Injury Rate Per Million Tons NFRPR	Total Number of Fatal Injuries FTL	Number of Disaster Fatalities DFTL	Fatal Injury Rate Per Million Man-Hours FRMH	Fatal Injury Rate Excluding Disaster Fatalities Per Million Man-Hours FRMHND
1950	591	100.773	66.6336	4	0	0.682053	0.682053
1951	836	129.659	75.1478	9	0	1.39585	1.39585
1952	716	112.598	71.3784	7	0	1.10081	1.10081
1953	988	138.766	83.6576	9	0	1.26406	1.26406
1954	548	90.4981	50.4881	13	0	2.14685	2.14685
1955	530	98.2615	51.8711	5	0	0.926996	0.926996
1956	696	86.1054	49.2293	7	0	0.866003	0.866003
1957	701	101.914	55.5515	3	0	0.436150	0.436150
1958	510	82.6155	46.8132	4	0	0.647965	0.647965
1959	424	88.6222	47.8424	7	0	1.46310	1.46310
1964	1013	246.921	98.2799	11	0	2.68127	2.68127
1965	591	130.909	46.7828	6	0	1.32902	1.32902
1966	442	103.563	31.2926	3	0	0.702920	0.702920
1967	731	147.290	47.8313	6	0	1.20895	1.20895
1968	653	124.593	37.9968	15	9	2.86202	1.14481
1969	663	115.741	34.5382	5	0	0.872855	0.872855
1970	737	112.891	39.2514	8	0	1.22541	1.22541
1971	591	78.2936	35.8922	5	0	0.662383	0.662383
1972	668	80.7129	41.7238	1	0	0.120828	0.120828
1973	616	65.9991	29.3517	8	0	0.857132	0.857132
1974	678	65.7879	34.3159	0	0	0.0	0.0
1975	1099	86.1729	50.3517	12	0	0.940923	0.940923

Table 141(Continued)

Year	Fatal Injury Rate Per Million Tons FRPR	Fatal Injury Rate Excluding Disaster Fatalities Per Million Tons FRPRND	Total Production TPROD X 10^{-6} (millions of short tons)	Number of Man-Days Worked MNDY X 10^{-6} (millions of man-days)	Weighted-Average Seam Thickness ST (inches)	Percent of Coal Loaded Mechanically PMECH	Weighted-Average Employment AEMPL	Average Production AP X 10^{6} (short tons)	Number of Inspections Per Mine Under CMHSA MACT
1950	0.450989	0.450989	8.86940	733081	65.27	48.66	87	385626	0.0
1951	0.809007	0.809007	11.1247	805961	63.92	56.63	92	463531	0.0
1952	0.697833	0.697833	10.0311	794866	64.54	61.42	104	477669	0.0
1953	0.762063	0.762063	11.8100	889990	63.45	66.74	106	513480	0.0
1954	1.19771	1.19771	10.8540	756922	63.46	74.31	94	493366	0.0
1955	0.489350	0.489350	10.2176	674221	65.77	69.69	80	444245	0.0
1956	0.495122	0.495122	14.1379	1010390	64.01	69.85	111	565517	0.0
1957	0.237738	0.237738	12.6189	859795	64.59	69.23	107	573587	0.0
1958	0.367163	0.367163	10.8944	771647	63.60	71.82	101	518779	0.0
1959	0.789851	0.789851	8.86243	598044	61.15	74.78	102	553902	0.0
1964	1.06720	1.06720	10.3073	512816	61.83	71.48	83	606312	0.0
1965	0.474953	0.474953	12.6328	564324	61.21	76.96	81	664886	0.0
1966	0.212393	0.212393	14.1247	533489	60.41	81.36	97	941649	0.0
1967	0.392596	0.392596	15.2829	620373	60.16	85.64	94	849049	0.0
1968	0.872822	0.349129	17.1856	655131	60.27	90.05	82	781166	0.0
1969	0.260469	0.260469	19.1961	716041	60.71	96.04	103	1010320	0.0
1970	0.426067	0.426067	18.7764	816053	61.05	91.89	106	894114	5.15924
1971	0.303657	0.303657	16.4660	943563	60.73	95.06	112	715912	10.4678
1972	0.624609	0.0624609	16.0100	1034530	61.48	97.14	129	727728	29.2330
1973	0.381191	0.381191	20.9868	1166680	61.37	98.39	145	953948	42.6833
1974	0.0	0.0	19.7576	1288230	61.13	99.44	168	940839	52.0947
1975	0.549791	0.549791	21.8265	1594180	62.36	99.61	208	1039360	39.1479

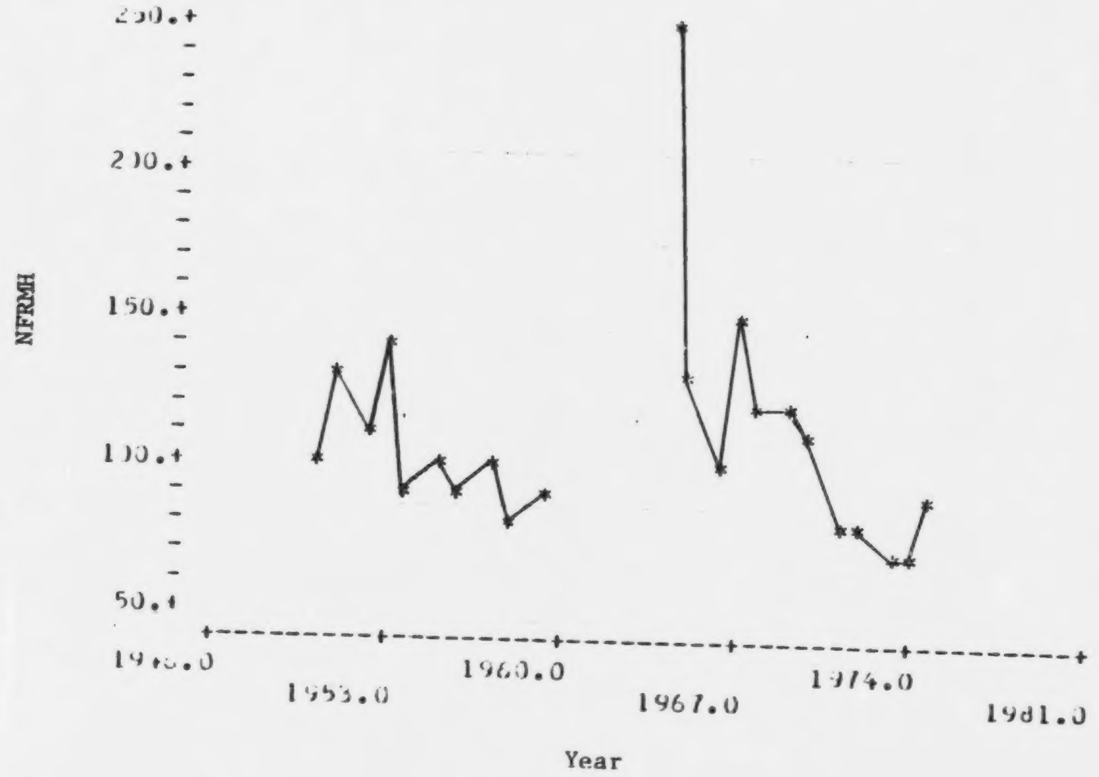


Figure 207. Trend of Nonfatal Injury Rate Per Million Man-Hours: Western Kentucky (1950 Through 1959 and 1964 Through 1975)

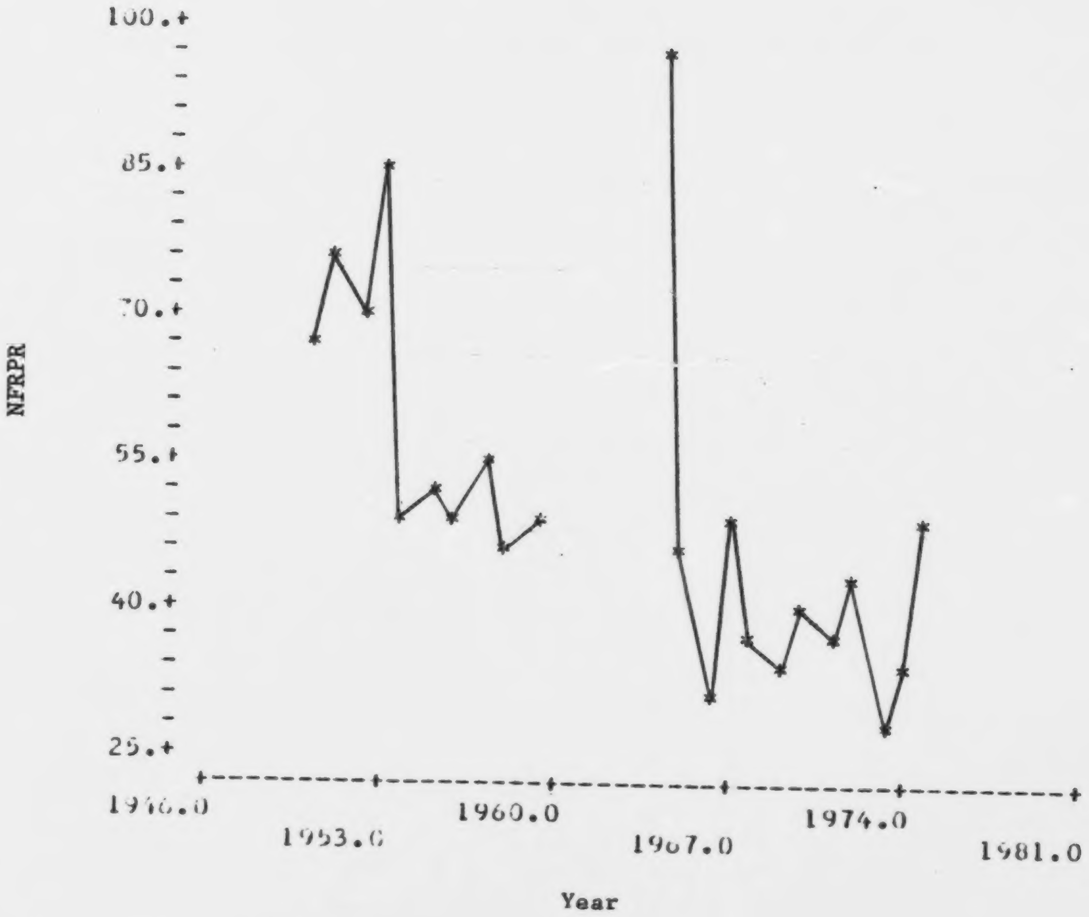


Figure 208. Trend of Nonfatal Injury Rate Per Million Tons: Western Kentucky (1950 Through 1959 and 1964 Through 1975)

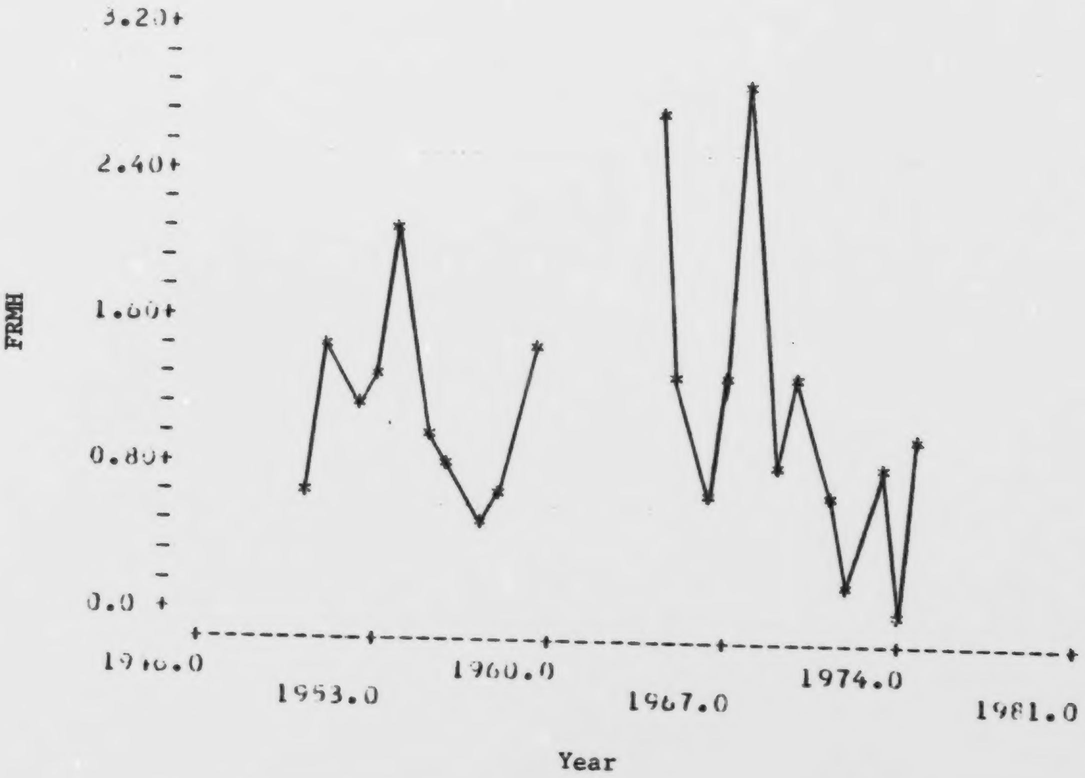


Figure 209. Trend of Fatal Injury Rate Per Million Man-Hours: Western Kentucky (1950 Through 1959 and 1964 Through 1975)

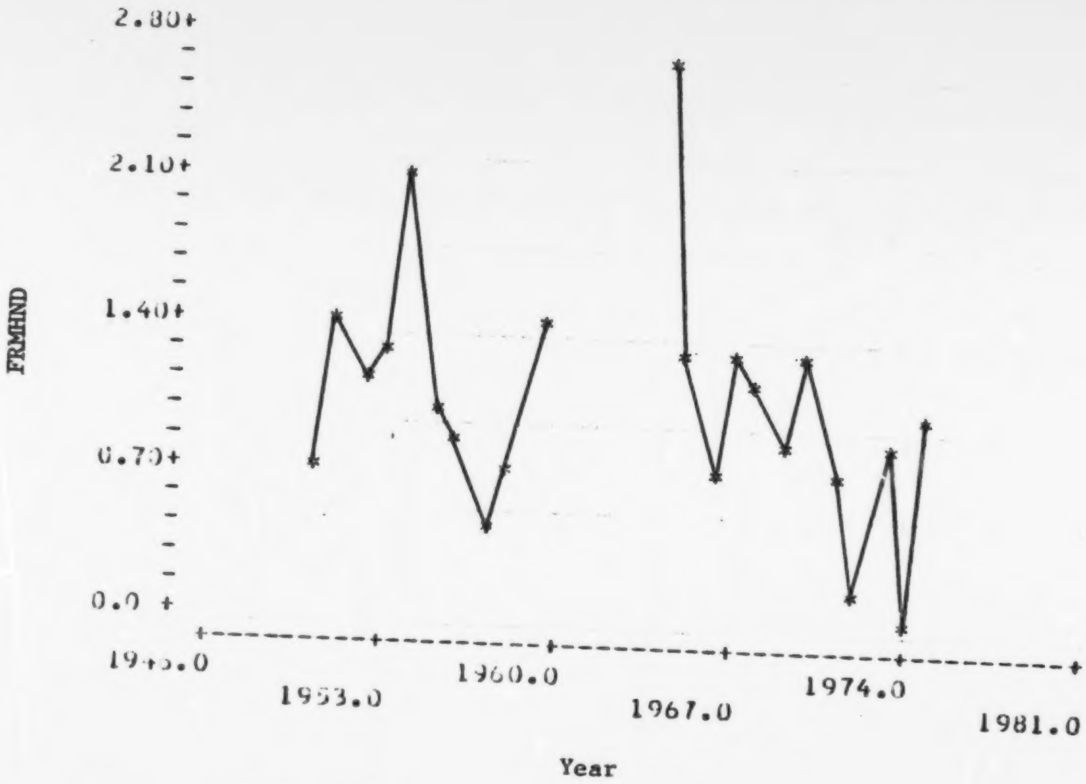


Figure 210. Trend of Fatal Injury Rate Excluding Disasters Per Million Man-Hours: Western Kentucky (1950 Through 1959 and 1964 Through 1975)

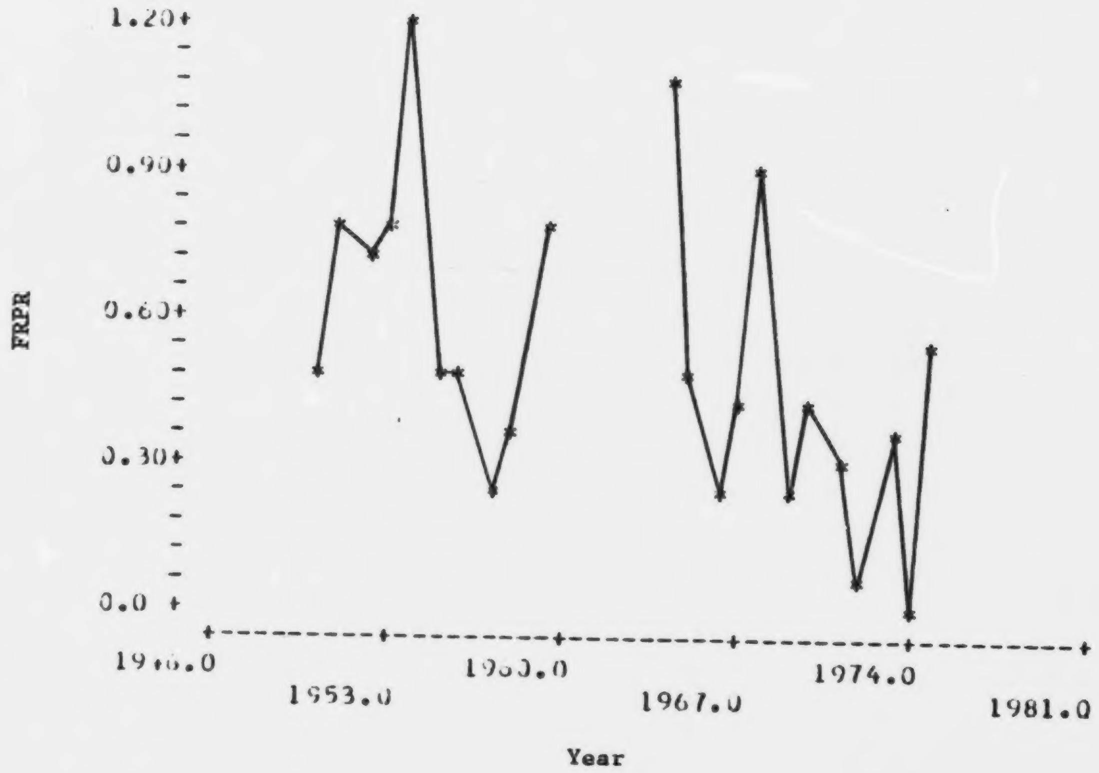


Figure 211. Trend of Fatal Injury Rate Per Million Tons: Western Kentucky (1950 Through 1959 and 1964 Through 1975)

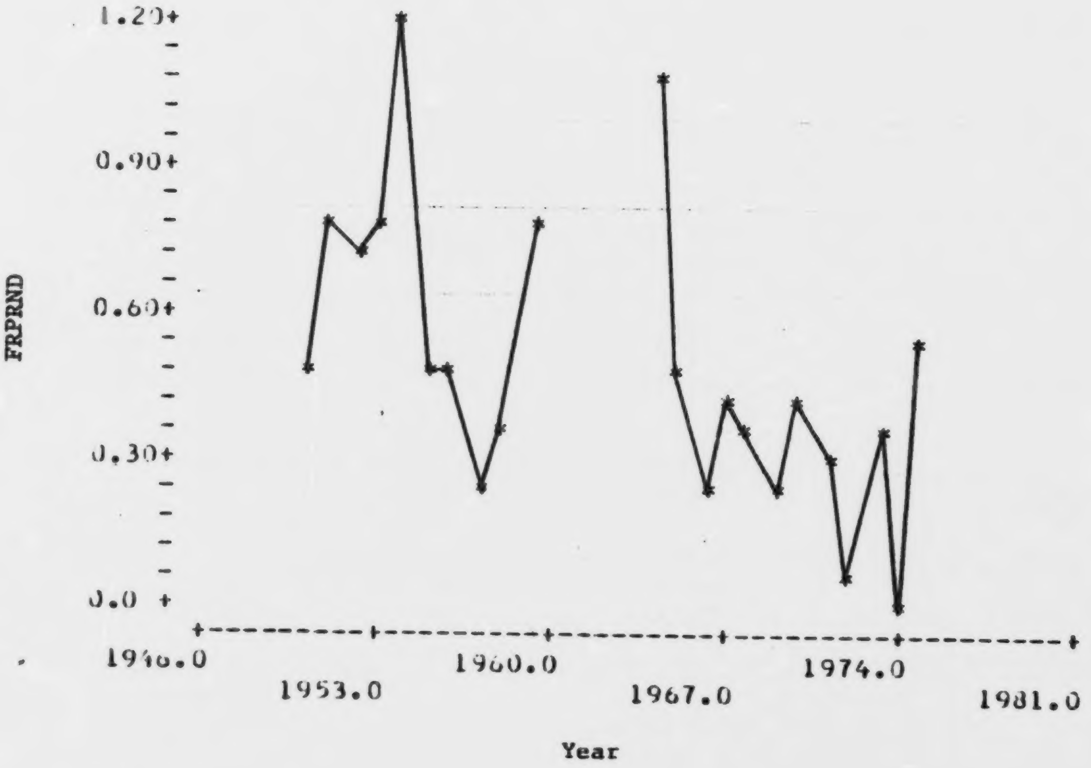


Figure 212. Trend of Fatal Injury Rate Excluding Disasters Per Million Tons: Western Kentucky (1950 Through 1959 and 1964 Through 1975)

Table 142

Piecewise Regression Results for Injury Rates: Western Kentucky Underground Rail-Connected Mines

Equation Dependent Variable	Constant	X_1	$X_1(X_2-20)$ Join Point of 1969	R^2	S	F-statistic
106 NFRMH	102.5 (16.0)	1.40 (1.28)	-13.70 (5.79) **	0.25	35.0	$3.10_{(2,19)}^{\ddagger}$
107 NFRPR	70.74 (6.71)	-1.520 (1.30) ***	1.30 (2.42)	0.39	14.6	$6.06_{(2,19)}$
108 FRMH	1.044 (0.307)	0.0203 (0.0244)	-0.223 (0.111) *	0.20	0.67	$2.36_{(2,19)}^{\ddagger}$
109 FRMHND	1.148 (0.259)	0.0012 (0.0207)	-0.1398 (0.0935)	0.18	0.57	$2.06_{(2,19)}^{\ddagger}$
110 FRPR	0.725 (0.130)	-0.0139 (0.0103)	-0.0231 (0.0467)	0.23	0.28	$2.89_{(2,19)}^{\ddagger}$
111 FRPRND	0.757 (0.121)	-0.01970 (0.00962) *	0.0023 (0.0435)	0.29	0.26	$3.93_{(2,19)}$

‡ The equation is not significant at the 95.0 percent confidence level or greater.

Significance Levels:
- * Significant at the 90.0 percent confidence level (two-tail test).
- ** Significant at the 95.0 percent confidence level (two-tail test).
- *** Significant at the 98.0 percent confidence level (two-tail test).

Kentucky. Weighted-average employment has an overall level trend from 1950 through 1969 or 1970, then an increasing trend thereafter (Figure 213). This break in trend is significant at the 99.0 percent confidence level.

Results of Regressions for 1950 Through 1975

Results of regressions for injury rates are presented in Tables 143 and 144. The pairwise correlation matrices are shown in Tables 145 and 146. The greatest correlations are between PMECH and AP (0.88) and AEMPL and MACT (0.87). Using the Cochrane-Orcutt iterative technique, there is no problem with autocorrelation; however, none of the equations for fatal injury rates are significant at the 95.0 percent confidence level. Appropriate plots are presented in Figures 214 through 219. There is no evidence for heteroskedasticity.

The equation for NFRMH explains 56.0 percent of the variance, and all variables except ST are significant. For NFRPR, 71.0 percent of the variance is explained; PMECH and AEMPL are significant. For fatal injury rates, 30.0, 28.0, 25.0, and 30.0 percent of the variance is explained for FRMH, FRMHND, FRPR, and FRPRND, respectively, and coefficients, in general, are not significant. Coefficients of ST are negative but not significant. Coefficients of PMECH are negative; they are significant for NFRMH, NFRPR, and FRPRND. Coefficients of AP are positive and significant for NFRMH and negative but not significant for FRMH and FRMHND. Coefficients of AEMPL are all positive and significant only for NFRPR. For MACT, coefficients are all negative as expected, but significant only for NFRMH.

Results of Regressions for 1964 Through 1975 for Underground Rail-Connected and Truck Mines

Data on all mines are shown in Table 147. Regression results are summarized in Tables 148 and 149. The correlation matrices are presented in

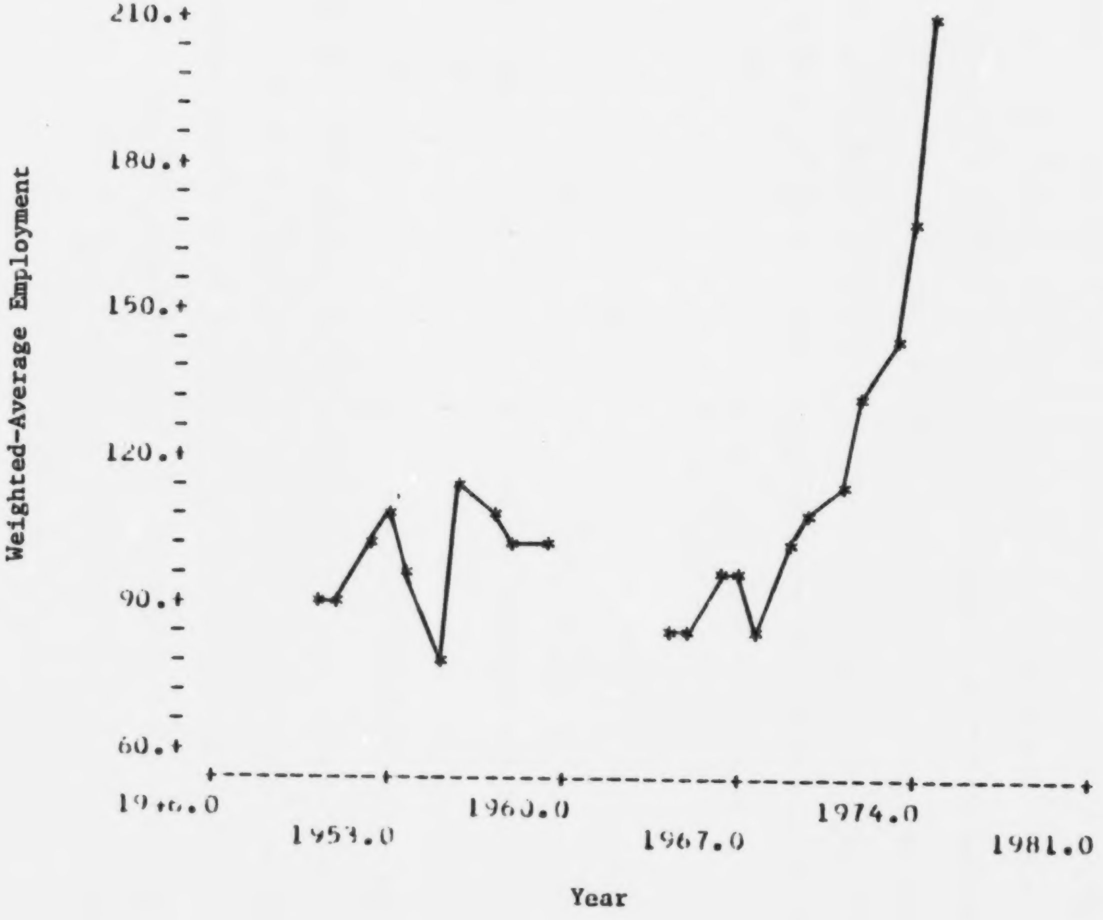


Figure 213. Trend of Weighted-Average Employment: Eastern Kentucky (1950 Through 1959 and 1964 Through 1975)

Table 143

Results of Regressions for Injury Model: Western Kentucky Underground Rail-Connected Mines
(1950 Through 1959 and 1964 Through 1975)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-correlation (Durbin-Watson Statistic)	F-Statistic
112 (OLS) NFRMH	963.531 (561.498)	-11.669 (7.916) #	-1.914 (1.301) #	43.004 (81.892)		-0.564 (0.707)	0.34	34.52	-(3.70)	$2.22^{\ddagger}_{(4,17)}$
113 (CORC) NFRMH	396.199 (308.634)	-3.733 (4.298)	-1.239 (0.795) #	63.862 (43.079) #		-0.717 (0.398) ##	0.56	17.77	None(2.19)	$4.77_{(4,15)}$
114 (OLS) NFRPR	263.503 (214.274)	-2.154 (3.046)	-1.211 (0.454) ####		0.169 (0.207)	-0.020 (0.401)	0.53	13.56	-(2.94)	$4.79_{(4,17)}$
115 (CORC) NFRPR	115.577 (147.951)	-0.161 (2.067)	-1.019 (0.338) #####		0.239 (0.137) #	-0.140 (0.279)	0.71	8.82	None(1.69)	$9.12_{(4,15)}$
116 (OLS) FRMH	15.253 (10.723)	-0.210 (0.151) #	-0.002 (0.025)	-1.134 (1.564)		-0.016 (0.013)	0.30	0.66	None(2.29)	$1.84^{\ddagger}_{(4,17)}$

Table 143 (Continued)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-correlation (Durbin-Watson Statistic)	F-Statistic
117 (OLS) FRMBIND	12.192 (9.113)	-0.156 (0.128)	-0.012 (0.021)	-0.622 (1.329)		-0.010 (0.011)	0.28	0.56	None(2.36)	$1.63^{‡}_{(4,17)}$
118 (OLS) FRPR	3.532 (4.658)	-0.038 (0.066)	-0.10 (0.10)		0.002 (0.005)	-0.006 (0.009)	0.25	0.29	None(2.07)	$1.43^{‡}_{(4,17)}$
119 (OLS) FRPRND	3.256 (4.372)	-0.033 (0.062)	-0.012 (0.009) #		0.003 (0.004)	-0.006 (0.008)	0.30	0.28	None(1.94)	$1.82^{‡}_{(4,17)}$

‡The equation is not significant at the 95.0 percent confidence level or greater.

Significance Levels:
Significant at the 90.0 percent confidence level (one-tail test)
Significant at the 95.0 percent confidence level (one-tail test)
Significant at the 99.0 percent confidence level (one-tail test)
Significant at the 99.5 percent confidence level (one-tail test)

Table 144

Ninety-Five Percent Confidence Intervals for Coefficients in Western Kentucky Regressions of Injury Model: Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1975)

Equation Dependent Variable	ST		PMECH		AP		AEMPL		MACT	
112(OLS) NFRMH	-28.37	5.03	-4.66	0.83	-129.79	215.80			-2.06	0.93
113(CORC) NFRMH	-12.89	5.43	-2.93	0.46	-27.94	155.66			-1.57	0.13
114(OLS) NFRPR	-8.58	4.27	-2.17	-0.25			-0.27	0.61	-0.87	0.83
115(CORC) NFRPR	-4.57	4.24	-1.74	-0.30			-0.05	0.53	-0.73	0.45
116(OLS) FRMH	-0.53	0.11	-0.05	0.05	-4.43	2.17			-0.04	0.01
117(OLS) FRMHND	-0.43	0.11	-0.06	0.03	-3.43	2.18			-0.03	0.01
118(OLS) FRPR	-0.18	0.10	-0.31	0.11			-0.01	0.01	-0.02	0.01
119(OLS) FRPRND	-0.16	0.10	-0.03	0.01			-0.01	0.01	-0.02	0.01

Table 145

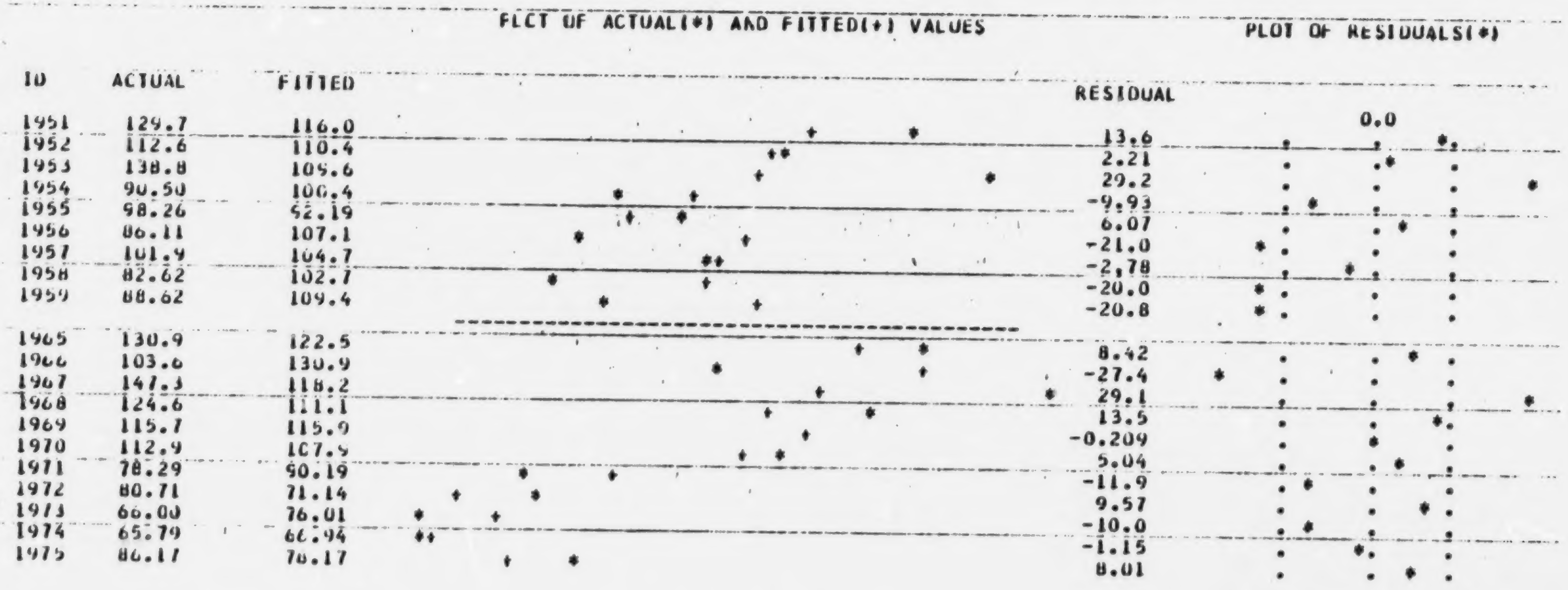
Pairwise Correlation Matrix for ST, PMECH, AP, and MACT: Western Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1975)

	ST	PMECH	AP	MACT
ST	1.0002	-0.75586	-0.76344	-0.26496
PMECH	-0.75586	1.0000	0.88043	0.65988
AP	-0.76344	0.88043	1.0000	0.57624
MACT	-0.26496	0.65988	0.57624	1.0000

Table 146

Pairwise Correlation Matrix for ST, PMECH, AEMPL, and MACT: Western Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1975)

	ST	PMECH	AEMPL	MACT
ST	1.0002	-0.75586	-0.15969	-0.26496
PMECH	-0.75586	1.0000	0.58652	0.65988
AEMPL	-0.15969	0.58652	1.0000	0.87187
MACT	-0.26496	0.65988	0.87187	1.0000



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                                   FLCT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED
                                                                          RESIDUAL
1951    129.7       116.0                                                                        0.0
1952    112.6       110.4                                                   13.6
1953    138.8       109.6                                                   2.21
1954    90.50       100.4                                                   29.2
1955    98.26       92.19                                                   -9.93
1956    86.11       107.1                                                   6.07
1957    101.9       104.7                                                   -21.0
1958    82.62       102.7                                                   -2.78
1959    88.62       109.4                                                   -20.0
                                                                            -20.8
1965    130.9       122.5
1966    103.6       130.9                                                   8.42
1967    147.3       118.2                                                   -27.4
1968    124.6       111.1                                                   29.1
1969    115.7       115.9                                                   13.5
1970    112.9       107.9                                                   -0.209
1971    78.29       90.19                                                   5.04
1972    80.71       71.14                                                   -11.9
1973    66.00       76.01                                                   9.57
1974    65.79       66.94                                                   -10.0
1975    86.17       78.17                                                   -1.15
                                                                            8.01
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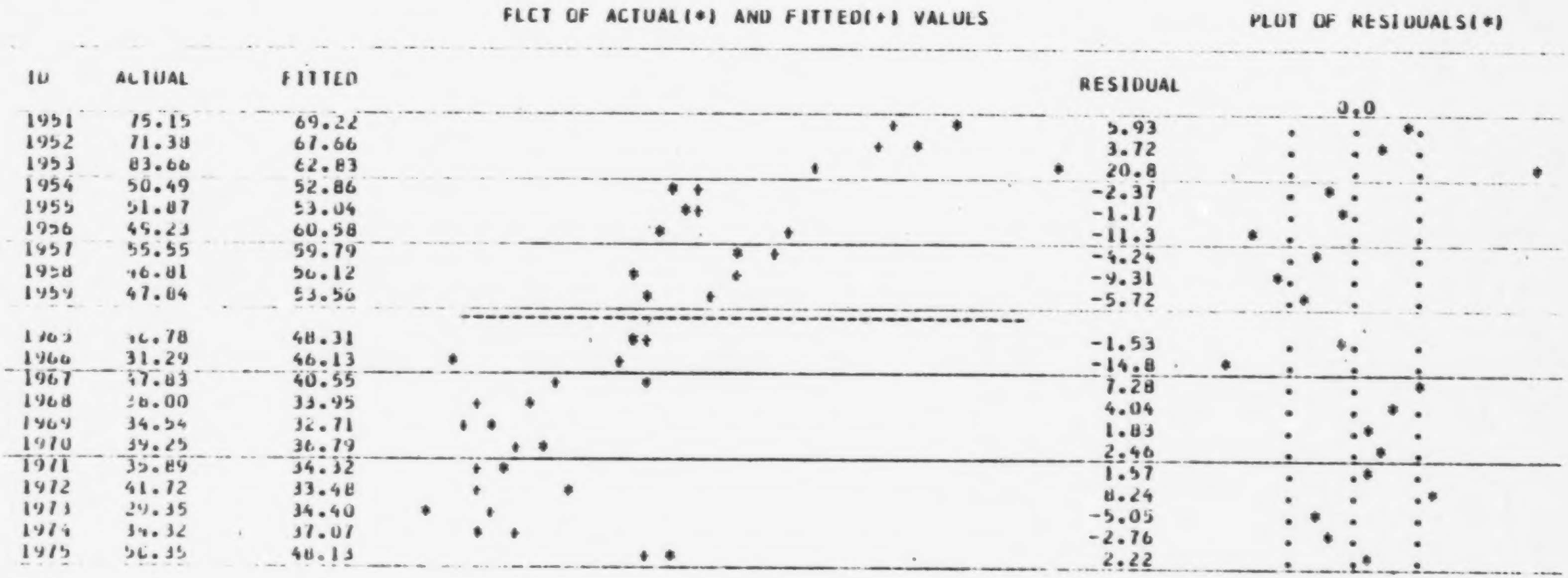
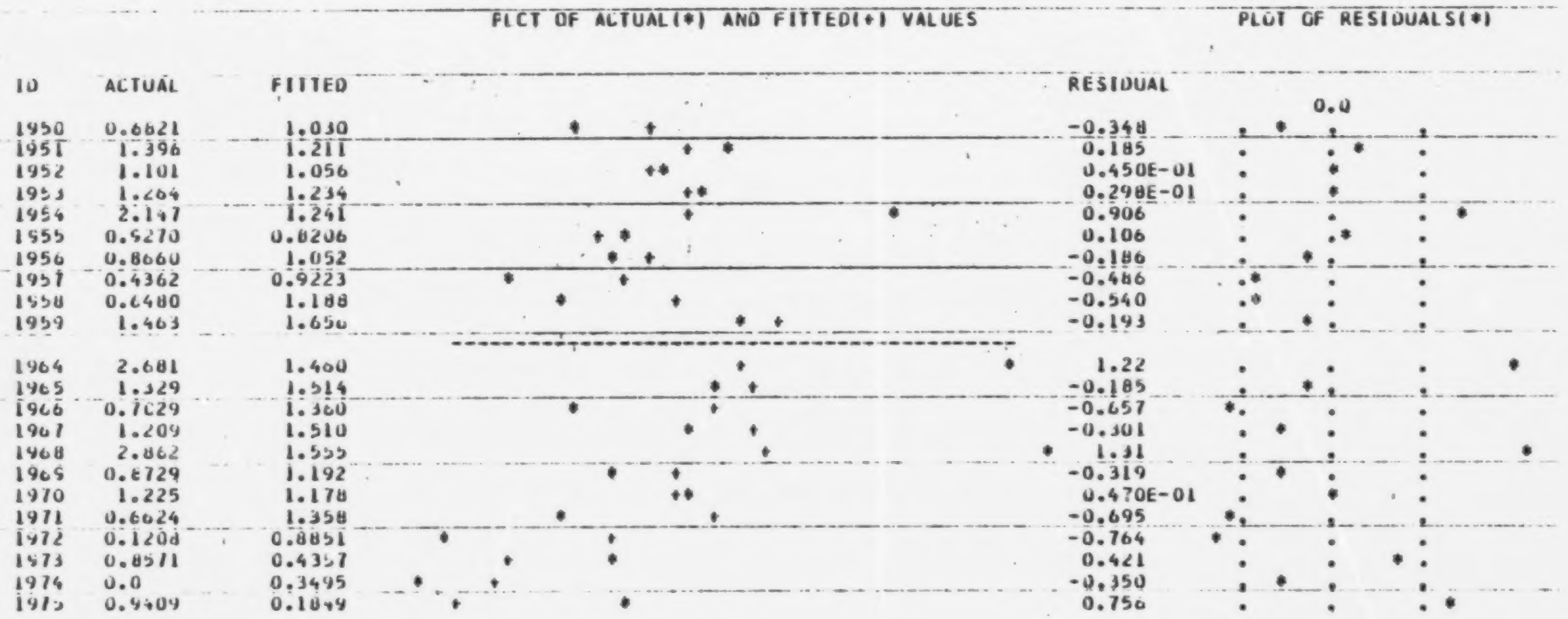
Figure 214. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (CORC)



ID	ACTUAL	FITTED	RESIDUAL
1951	75.15	69.22	5.93
1952	71.38	67.66	3.72
1953	83.66	62.83	20.8
1954	50.49	52.86	-2.37
1955	51.87	53.04	-1.17
1956	49.23	60.58	-11.3
1957	55.55	59.79	-4.24
1958	46.81	56.12	-9.31
1959	47.84	53.56	-5.72
1965	46.78	48.31	-1.53
1966	31.29	46.13	-14.8
1967	47.83	40.55	7.28
1968	38.00	33.95	4.04
1969	34.54	32.71	1.83
1970	39.25	36.79	2.46
1971	35.89	34.32	1.57
1972	41.72	33.48	8.24
1973	29.35	34.40	-5.05
1974	34.32	37.07	-2.76
1975	50.35	48.13	2.22

Figure 215. Plots for Nonfatal Injury Rate Per Million Tons, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (CORC)



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                              PLCT OF ACTUAL(*) AND FITTED(+) VALUES                 PLOT OF RESIDUALS(*)

ID     ACTUAL       FITTED                                          RESIDUAL
                                                                                       0.0
1950   0.6621       1.030                                           -0.348
1951    1.396       1.211                                            0.185
1952    1.101       1.056                                            0.450E-01
1953    1.264       1.234                                            0.298E-01
1954    2.147       1.241                                            0.906
1955   0.9270      0.8206                                            0.106
1956   0.8660       1.052                                           -0.186
1957   0.4362      0.9223                                           -0.486
1958   0.6480       1.188                                           -0.540
1959    1.463       1.650                                           -0.193

1964    2.681       1.460                                            1.22
1965    1.329       1.514                                           -0.185
1966   0.7029       1.360                                           -0.657
1967    1.209       1.510                                           -0.301
1968    2.862       1.555                                            1.31
1969   0.8729       1.192                                           -0.319
1970    1.225       1.178                                            0.470E-01
1971   0.6624       1.358                                           -0.695
1972   0.1208      0.8851                                           -0.764
1973   0.8571      0.4357                                            0.421
1974   0.0         0.3495                                           -0.350
1975   0.9409      0.1849                                            0.756
```
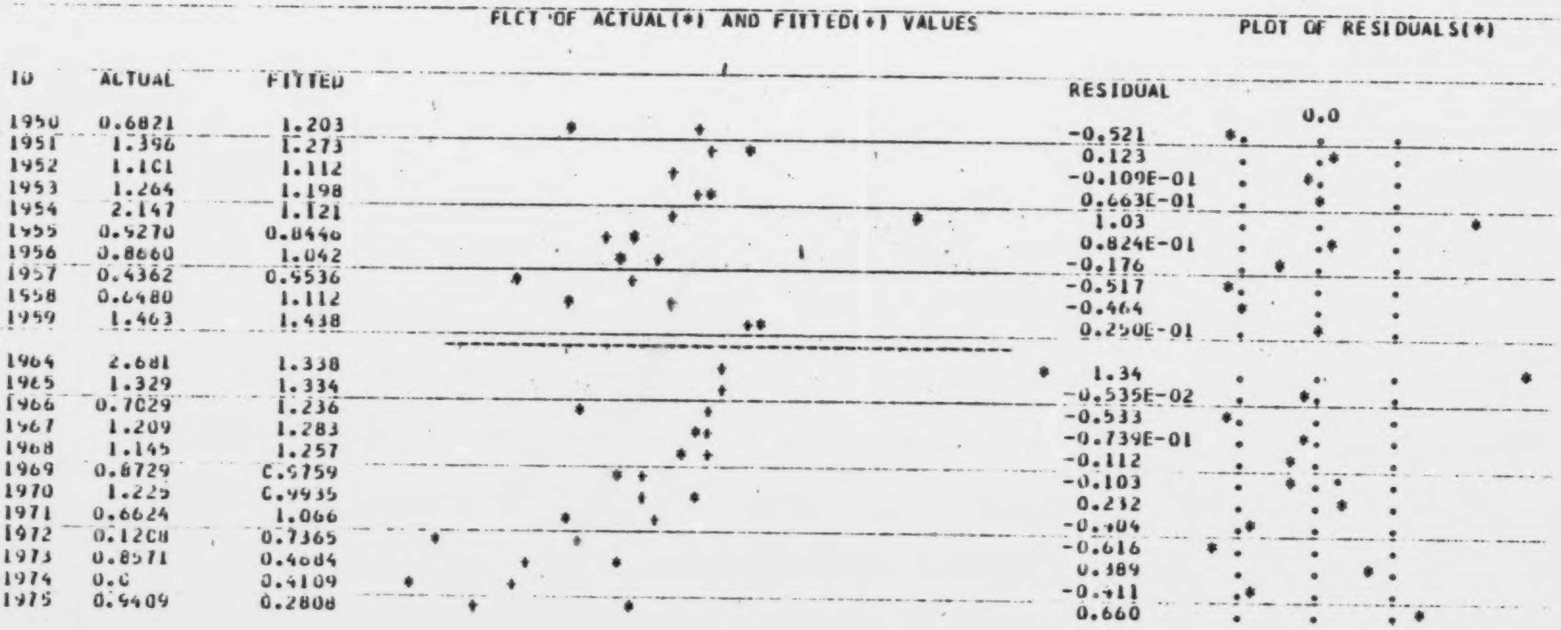

Figure 216. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (OLS)



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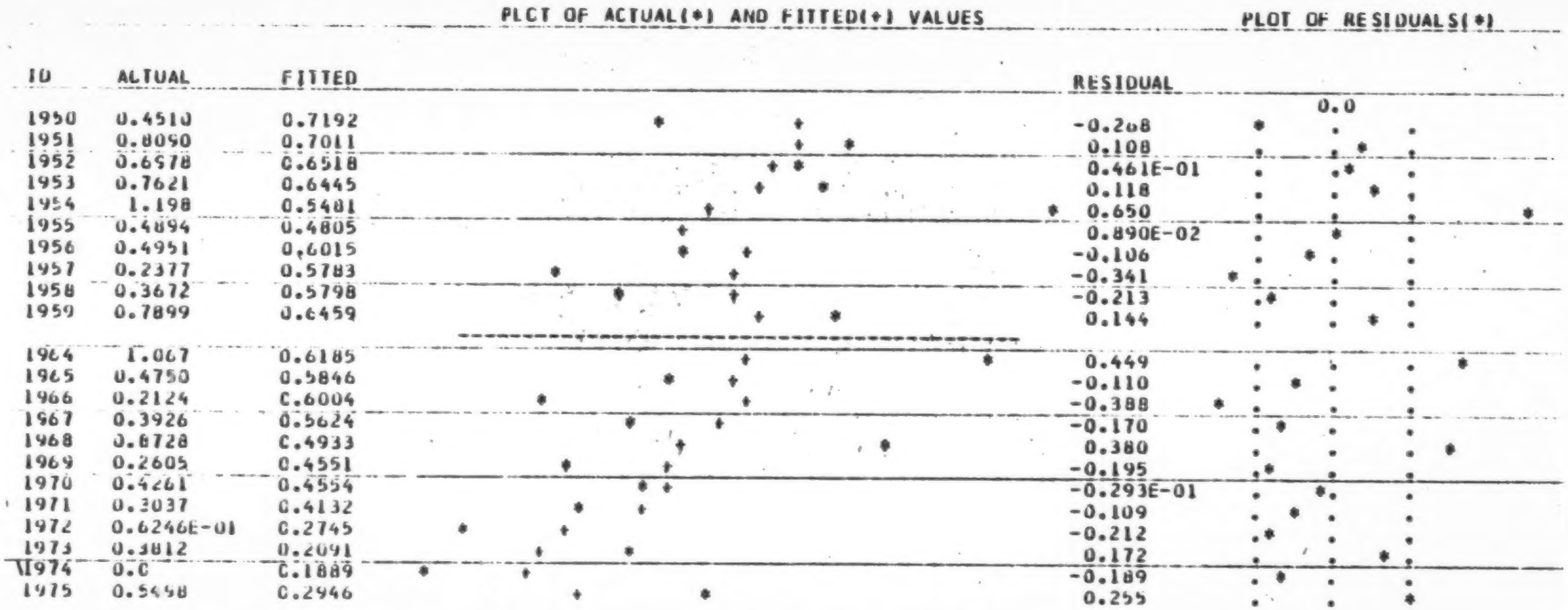
                              PLOT OF ACTUAL(*) AND FITTED(+) VALUES                 PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                              RESIDUAL
                                                                                        0.0
1950    0.6821      1.203                                               -0.521
1951    1.396       1.273                                                0.123
1952    1.101       1.112                                               -0.109E-01
1953    1.264       1.198                                                0.663E-01
1954    2.147       1.121                                                1.03
1955    0.9270      0.8446                                               0.824E-01
1956    0.8660      1.042                                               -0.176
1957    0.4362      0.9536                                              -0.517
1958    0.6480      1.112                                               -0.464
1959    1.463       1.438                                                0.250E-01

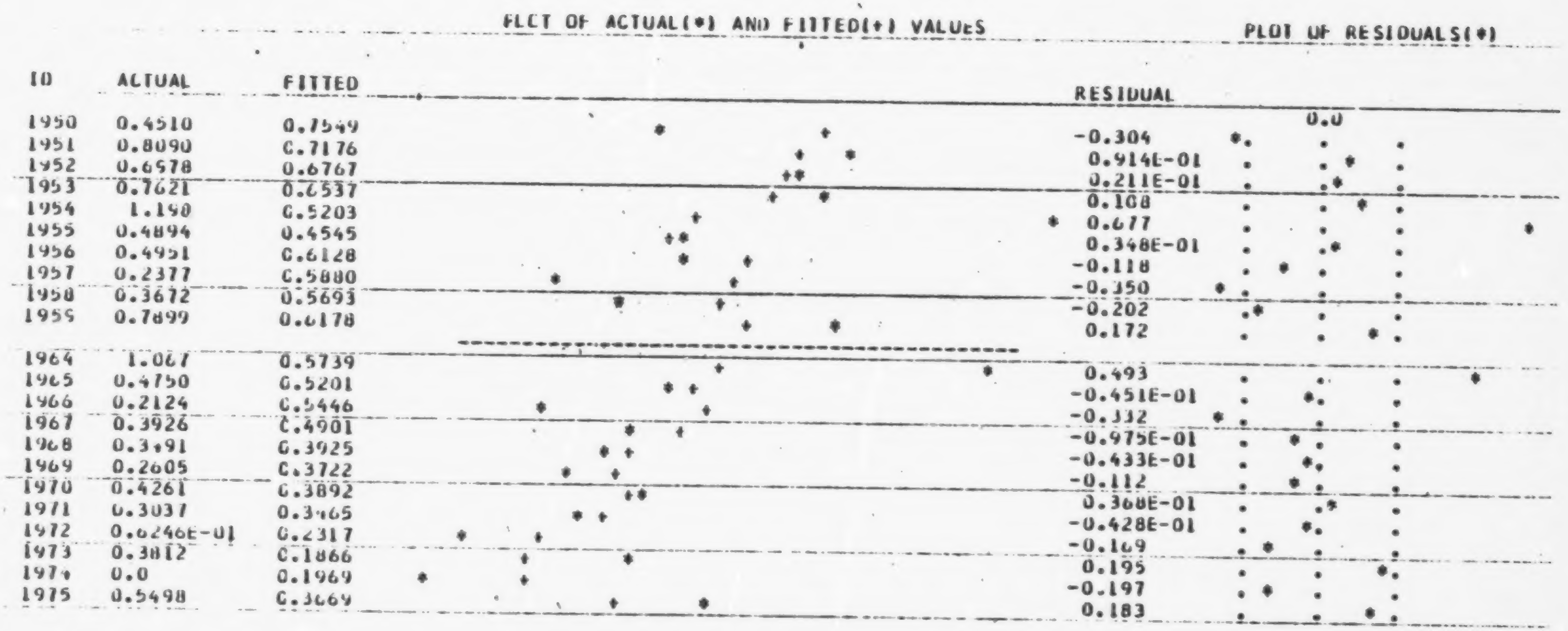
1964    2.681       1.338                                                1.34
1965    1.329       1.334                                               -0.535E-02
1966    0.7029      1.236                                               -0.533
1967    1.209       1.283                                               -0.739E-01
1968    1.145       1.257                                               -0.112
1969    0.8729      0.9759                                              -0.103
1970    1.225       0.9935                                               0.232
1971    0.6624      1.066                                               -0.404
1972    0.1208      0.7365                                              -0.616
1973    0.8571      0.4684                                               0.389
1974    0.0         0.4109                                              -0.411
1975    0.9409      0.2808                                               0.660
```

Figure 217. Plots for Fatal Injury Rate Excluding Disasters Per Million Man-Hours, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (OLS)



ID	ACTUAL	FITTED	RESIDUAL
1950	0.4510	0.7192	-0.268
1951	0.8090	0.7011	0.108
1952	0.6978	C.6518	0.461E-01
1953	0.7621	0.6445	0.118
1954	1.198	0.5481	0.650
1955	0.4894	0.4805	0.890E-02
1956	0.4951	0,6015	-0.106
1957	0.2377	0.5783	-0.341
1958	0.3672	0.5798	-0.213
1959	0.7899	0.6459	0.144
1964	1.067	0.6185	0.449
1965	0.4750	0.5846	-0.110
1966	0.2124	C.6004	-0.388
1967	0.3926	0.5624	-0.170
1968	0.8728	C.4933	0.380
1969	0.2605	0.4551	-0.195
1970	0.4261	0.4554	-0.293E-01
1971	0.3037	C.4132	-0.109
1972	0.6246E-01	C.2745	-0.212
1973	0.3812	0.2091	0.172
1974	0.C	C.1889	-0.189
1975	0.5498	C.2946	0.255

Figure 218. Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (OLS)



ID	ACTUAL	FITTED	RESIDUAL
1950	0.4510	0.7549	-0.304
1951	0.8090	0.7176	0.914E-01
1952	0.6978	0.6767	0.211E-01
1953	0.7621	0.6537	0.108
1954	1.198	0.5203	0.677
1955	0.4894	0.4545	0.348E-01
1956	0.4951	0.6128	-0.118
1957	0.2377	0.5880	-0.350
1958	0.3672	0.5693	-0.202
1959	0.7899	0.6178	0.172
1964	1.067	0.5739	0.493
1965	0.4750	0.5201	-0.451E-01
1966	0.2124	0.5446	-0.332
1967	0.3926	0.4901	-0.975E-01
1968	0.3491	0.3925	-0.433E-01
1969	0.2605	0.3722	-0.112
1970	0.4261	0.3892	0.368E-01
1971	0.3037	0.3465	-0.428E-01
1972	0.6246E-01	0.2317	-0.169
1973	0.3812	0.1866	0.195
1974	0.0	0.1969	-0.197
1975	0.5498	0.3669	0.183

Figure 219. Plots for Fatal Injury Rate Excluding Disasters Per Million Tons, 1950 Through 1959 and 1964 Through 1975: Western Kentucky (OLS)

Table 147

Data for Western Kentucky Injury Model: Underground Rail-Connected and Truck Mines

Year	Number of Nonfatal Injuries NFTL	Nonfatal Injury Rate Per Million Man-Hours NFRMH	Nonfatal Injury Rate Per Million Tons NFRPR	Total Number of Fatal Injuries FTL	Number of Disaster Fatalities DFTL	Fatal Injury Rate Per Million Man-Hours FRMH	Fatal Injury Rate Excluding Disaster Fatalities Per Million Man-Hours FRMIND
1964	1308	253.536	104.054	12	0	2.32601	2.32601
1965	628	126.770	47.0715	6	0	1.21118	1.21118
1966	495	102.823	33.2112	6	0	1.24634	1.24634
1967	819	150.638	50.9128	7	0	1.28750	1.28750
1968	699	124.463	39.2586	15	9	2.67087	1.06835
1969	682	113.068	34.3855	7	0	1.16052	1.16052
1970	771	110.626	39.6799	8	0	1.14787	1.14787
1971	639	79.8564	36.7662	5	0	0.624855	0.624855
1972	734	84.2504	43.0847	2	0	0.229565	0.229565
1973	675	68.5441	30.3204	8	0	0.812375	0.812375
1974	749	67.6004	34.6389	0	0	0.0	0.0
1975	1161	83.6576	46.9742	14	0	1.00879	1.00879

Table 147 (Continued)

Year	Fatal Injury Rate Per Million Tons FRPR	Fatal Injury Rate Excluding Disaster Fatalities Per Million Tons FRPRND	Total Production TPROD x 10^{-6} (millions of short tons)	Number of Man-Days Worked MNDY (millions of man-days)	Weighted-Average Seam Thickness ST (inches)	Percent of Coal Loaded Mechanically PMECH	Weighted-Average Employment AEMPL	Average Production AP x 10^{6} (short tons)	Number of Inspections Per Mine Under CMHSA MACT
1964	0.954627	0.954627	12.5703	644880	61.53	71.48	38	267454	0.0
1965	0.449728	0.449728	13.3414	619230	61.08	76.96	37	290031	0.0
1966	0.402560	0.402560	14.9046	601762	60.48	81.36	39	354872	0.0
1967	0.435153	0.435153	16.0863	679611	60.28	85.64	45	392349	0.0
1968	0.842460	0.336984	17.8050	702018	60.34	90.05	51	468553	0.0
1969	0.352930	0.352930	19.8340	763969	60.76	96.04	69	661132	0.0
1970	0.411724	0.411724	19.4305	871180	61.07	91.89	75	607203	5.15924
1971	0.287686	0.287686	17.3801	100023=	60.71	95.06	88	560648	10.4678
1972	0.117397	0.117397	17.0362	108902=	61.63	97.14	103	587455	29.2330
1973	0.359353	0.359353	22.2622	123096=	61.47	98.39	125	824527	42.6833
1974	0.0	0.0	21.6231	138498=	61.23	99.44	146	831658	52.0947
1975	0.566442	0.566442	24.7157	173475=	62.32	99.61	176	915396	39.1479

Table 148

Results of Regressions for Injury Model: Western Kentucky Underground Rail-Connected and Truck Mines (1964 Through 1975)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	MACT	R^2	S	Auto-correlation (Durbin-Watson Statistic)	F-Statistic
120(OLS) NFRMH	-629.885 (1723.80)	19.009 (26.251)	-4.948 (3.218) #	78.087 (168.668)		-0.982 (1.009)	0.73	33.19	None(1.97)	$4.70_{(4,7)}$
121(OLS) NFRPR	-760.268 (900.474)	15.654 (13.918)	-1.713 (1.109) #		0.085 (0.411)	-0.209 (0.554)	0.68	13.95	None(2.06)	$3.69^{‡}_{(4,7)}$
122(OLS) FRMH	11.240 (32.395)	-0.078 (0.493)	-0.076 (0.060)	3.404 (3.170)		-0.030 (0.019) #	0.57	0.62	None(2.30)	$2.30^{‡}_{(4,7)}$
123(OLS) FRMHND	-2.731 (12.523)	0.165 (0.191)	-0.089 (0.023) #####	3.643 (1.225) **		-0.027 (0.007) #####	0.89	0.24	None(2.31)	$14.45_{(4,7)}$
124(OLS) FRPR	-0.476 (14.695)	0.042 (0.227)	-0.021 (0.018)		0.006 (0.007)	-0.014 (0.009) #	0.53	0.23	None(2.31)	$2.01^{‡}_{(4,7)}$
125(OLS) FRPRND	-5.758 (8.773)	0.131 (0.136)	-0.024 (0.011) ##		0.006 (0.004)	-0.012 (0.005) ##	0.78	0.14	None(2.74)	$6.35_{(4,7)}$

‡ The equation is not significant at the 95.0 percent confidence level or greater.

Significance Levels:
** Significant at the 95.0 percent confidence level (two-tail test)
# Significant at the 90.0 percent confidence level (one-tail test)
Significant at the 95.0 percent confidence level (one-tail test)
Significant at the 99.5 percent confidence level (one-tail test)

Table 149

Ninety-Five Percent Confidence Intervals for Coefficients in Western Kentucky Regressions of Injury Model: Underground Rail-Connected and Truck Mines (1964 Through 1975)

Equation Dependent Variable	ST		PMECH		AP		AEMPL		MACT	
120(OLS) NFRMH	-43.07	81.09	-12.56	2.66	-476.99	476.99			-3.37	1.4
121(OLS) NFRPR	-17.26	48.57	-4.34	0.91			-0.89	1.06	-1.52	1.1
122(OLS) FRMH	-1.24	1.09	-0.22	0.07	-4.09	10.90			-0.07	0.0
123(OLS) FRMHND	-0.29	0.62	-0.14	-0.03	0.75	6.54			-0.04	-0.01
124(OLS) FRPR	-0.49	0.58	-0.06	0.02			-0.01	0.02	-0.04	0.01
125(OLS) FRPRND	-0.19	0.45	-0.05	0.00			-0.00	0.02	-0.02	-0.00

Tables 150 and 151. Equations for NFRPR, FRMH, and FRPR are not significant at the 95.0 percent confidence level or greater. These results will be compared to those for rail-connected mines in the summary part of this section.

Results of Regressions for Underground Rail-Connected Mines Using Data Through 1969 and Predictions of Productivity

In this section, results on data through 1969 are presented, and predictions of injury rates are made assuming there is no CMHSA. Trends of the independent variables suggest they are not affected by the Mine Act. Results of regressions are presented in Tables 152 and 153; correlation matrices are presented in Tables 154 and 155. The greatest pairwise correlation is between AP and PMECH (0.87). Only the equations for NFRPR and FRMH are significant, however, with R^2 values of 0.66 and 0.49, respectively. Values of R^2 for NFRMH, FRMHND, FRPR, and FRPRND are 0.25, 0.44, 0.16, and 0.27, respectively. Appropriate plots are shown in Figures 220 through 225. Coefficients of ST are negative but significant only for FRMH and FRMHND. PMECH is significant and negative only for NFRPR and FRPRND. The only significant mine-size coefficients are for FRMH and FRMHND; they are negative, as expected.

Predictions of injury rates using these results are presented in Table 156. Prediction intervals are wide; thus, most actual values fall within prediction intervals. The only significant differences are for FRMH, actual values are significantly less than predicted in 1971 and 1972. Otherwise, actual values are less than predicted in less than one-half the cases. Actual injury rates per million tons (NFRPR, FRPR, and FRPRND) have greater values than predicted in most years.

Data for all mines cannot be used for predictions since there are only six observations.

Table 150

Pairwise Correlation Matrix for ST, PMECH, AP, and MACT: Western Kentucky Underground Rail-Connected and Truck Mines (1964 Through 1975)

	ST	PMECH	AP	MACT
ST	1.0004	0.27261	0.52678	0.64880
PMECH	0.27261	1.0000	0.91170	0.70160
AP	0.52678	0.91170	1.0000	0.83224
MACT	0.64880	0.70160	0.83224	1.0000

Table 151

Pairwise Correlation Matrix for ST, PMECH, AEMPL, and MACT: Western Kentucky Underground Rail-Connected and Truck Mines (1964 Through 1975)

	ST	PMECH	AEMPL	MACT
ST	1.0004	0.27261	0.69964	0.64880
PMECH	0.27261	1.0000	0.81055	0.70160
AEMPL	0.69964	0.81055	1.0000	0.91986
MACT	0.64880	0.70160	0.91986	1.0000

Table 152

Results of Regressions for Injury Model: Western Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1969)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	R^2	S	Auto-correlation (Durbin-Watson Statistic)	F-Statistic
126(OLS) NFRMH	1169.28 (720.936)	-14.847 (10.247) #	-1.559 (1.813)	-8.398 (127.971)		0.18	39.87	-(3.64)	$0.89^{\ddagger}_{(3,12)}$
127(CORC) NFRMH	490.952 (399.849)	-5.153 (5.614)	-1.168 (1.170)	46.232 (69.598)		0.25	20.67	None(2.04)	$1.11^{\ddagger}_{(3,10)}$
128(OLS) NFRPR	320.921 (251.365)	-2.529 (3.524)	-1.312 (0.560) ###		-0.113 (0.394)	0.44	15.33	None(2.78)	$3.18^{\ddagger}_{(3,12)}$
129(CORC) NFRPR	184.882 (180.247)	-0.848 (2.424)	-1.222 (0.433) ####		0.120 (0.285)	0.66	10.07	None(1.61)	$6.38_{(3,10)}$
130(OLS) FRMH	26.187 (10.250)	-0.386 (0.146) ##	0.034 (0.026)	-5.058 (1.819) ####		0.49	0.57	None(1.97)	$3.85_{(3,12)}$
131(OLS) FRMIND	22.047 (9.097)	-0.309 (0.129) ###	0.011 (0.023)	-3.694 (1.615) ###		0.38	0.50	None(2.39)	$2.48^{\ddagger}_{(3,12)}$
132(CORC) FRMIND	15.355 (7.047)	-0.212 (0.100) ##	0.012 (0.021)	-2.964 (1.220) ###		0.44	0.36	None(1.50)	$2.63^{\ddagger}_{(3,10)}$

Table 152 (Continued)

Equation Dependent Variable	Constant	ST	PMECH	AP	AEMPL	R^2	S	Auto-correlation (Durbin-Watson Statistic)	F-Statistic
133(OLS) FRPR	4.264 (5.091)	-0.937 (0.071)	-0.009 (0.011)		-0.007 (0.008)	0.12	0.31	None(1.83)	$0.57^{\ddagger}_{(3,12)}$
134(CORC FRPR	4.671 (5.412)	-0.037 (0.073)	-0.014 (0.013)		-0.007 (0.008)	0.16	0.30	None(1.82)	$0.65^{\ddagger}_{(3,10)}$
135(OLS) FRPRND	4.074 (4.956)	-0.036 (0.069)	-0.013 (0.011)		-0.003 (0.008)	0.15	0.30	None(1.71)	$0.71^{\ddagger}_{(3,12)}$
136(CORC) FRPRND	4.605 (5.128)	-0.040 (0.068)	-0.019 (0.012) #		-0.002 (0.008)	0.27	0.27	None(1.71)	$1.22^{\ddagger}_{(3,10)}$

‡The equation is not significant at the 95.0 percent confidence level or greater.

Significance Levels:
- # Significant at the 90.0 percent confidence level (one-tail test)
- ## Significant at the 95.0 percent confidence level (one-tail test)
- ### Significant at the 97.5 percent confidence level (one-tail test)
- #### Significant at the 99.0 percent confidence level (one-tail test)

Table 153

Ninety-Five Percent Confidence Intervals for Coefficients in Western Kentucky Regressions of Injury Model: Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1969)

Equation Dependent Variable	ST		PMECH		AP		AEMPL	
126(OLS) NFRMH	-37.18	7.48	-5.51	2.39	-287.25	270.45		
127(CORC) NFRMH	-17.66	7.35	-3.77	1.44	-108.83	201.30		
128(OLS) NFRPR	-10.21	5.15	-2.53	-0.09			-0.97	0.75
129(CORC) NFRPR	-6.25	4.55	-2.19	-0.26			-0.51	0.75
130(OLS) FRMH	-0.70	-0.07	-0.02	0.09	-9.02	-1.09		
131(OLS) FRMHND	-0.59	-0.03	-0.04	0.06	-7.21	-0.17		
132(CORC) FRMHND	-0.43	0.01	-0.03	0.06	-5.68	-0.25		
133(OLS) FRPR	-0.19	0.12	-0.03	0.01			-0.02	0.01
134(CORC) FRPR	-0.20	0.13	-0.04	0.01			-0.02	0.01
135(OLS) FRPRND	-0.19	0.11	-0.04	0.01			-0.02	0.01
136(CORC) FRPRND	-0.19	0.11	-0.05	0.01			-0.02	0.02

Table 154

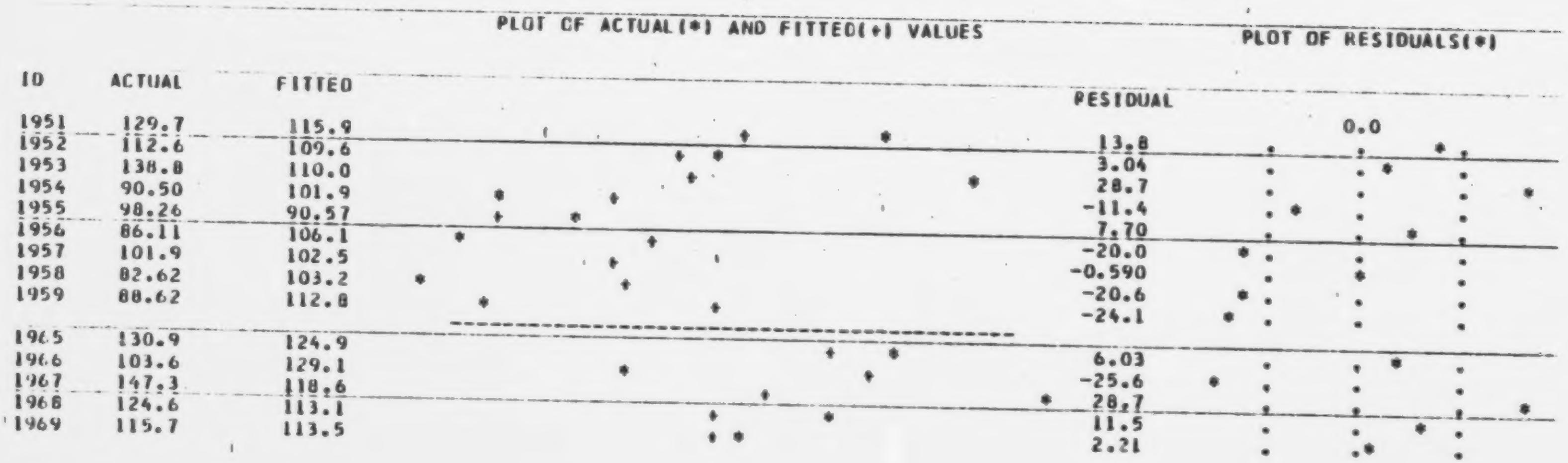
Pairwise Correlation Matrix for ST, PMECH, and AP: Western Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1969)

	ST	PMECH	AP
ST	1.0002	-0.80285	-0.83813
PMECH	-0.80285	1.0000	0.86945
AP	-0.83813	0.86945	1.0000

Table 155

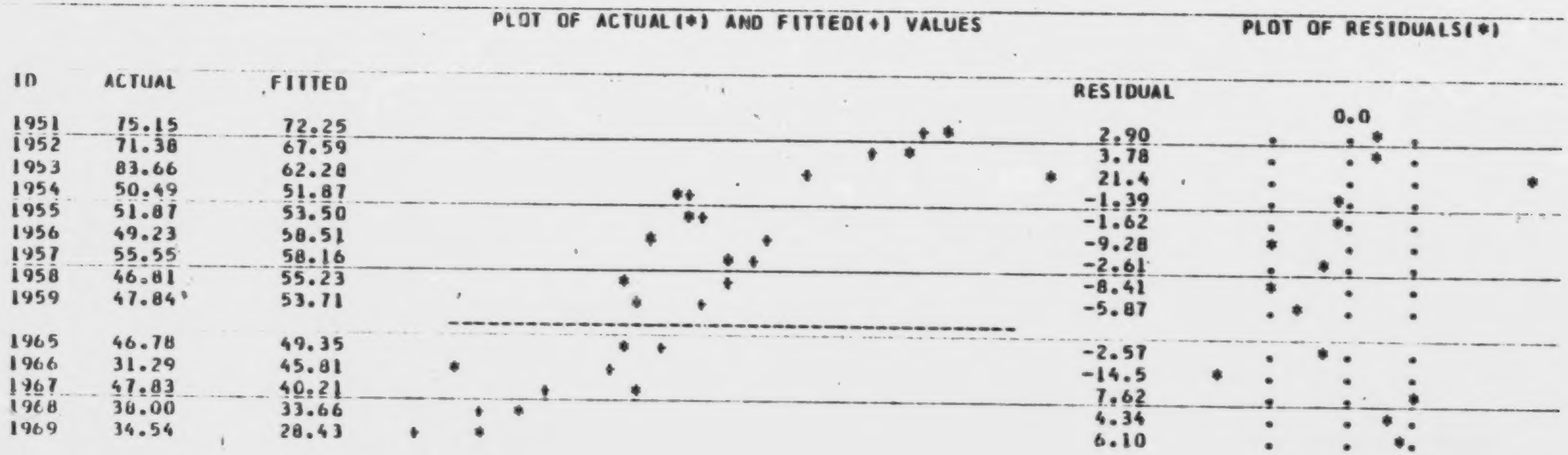
Pairwise Correlation Matrix for ST, PMECH, and AEMPL: Western Kentucky Underground Rail-Connected Mines (1950 Through 1959 and 1964 Through 1969)

	ST	PMECH	AEMPL
ST	1.0002	-0.80285	0.12489
PMECH	-0.80285	1.0000	-0.022282
AEMPL	0.12489	-0.022282	1.0000



ID	ACTUAL	FITTED	RESIDUAL
1951	129.7	115.9	13.8
1952	112.6	109.6	3.04
1953	138.8	110.0	28.7
1954	90.50	101.9	-11.4
1955	98.26	90.57	7.70
1956	86.11	106.1	-20.0
1957	101.9	102.5	-0.590
1958	82.62	103.2	-20.6
1959	88.62	112.8	-24.1
1965	130.9	124.9	6.03
1966	103.6	129.1	-25.6
1967	147.3	118.6	28.7
1968	124.6	113.1	11.5
1969	115.7	113.5	2.21

Figure 220. Plots for Nonfatal Injury Rate Per Million Man-Hours, 1950 Through 1959 and 1964 Through 1969: Western Kentucky (CORC)



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                                    PLOT OF ACTUAL(*) AND FITTED(+) VALUES          PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                                RESIDUAL
                                                                                         0.0
1951    75.15       72.25                                                   2.90
1952    71.38       67.59                                                   3.78
1953    83.66       62.28                                                   21.4
1954    50.49       51.87                                                  -1.39
1955    51.87       53.50                                                  -1.62
1956    49.23       58.51                                                  -9.28
1957    55.55       58.16                                                  -2.61
1958    46.81       55.23                                                  -8.41
1959    47.84       53.71                                                  -5.87

1965    46.78       49.35                                                  -2.57
1966    31.29       45.81                                                 -14.5
1967    47.83       40.21                                                   7.62
1968    38.00       33.66                                                   4.34
1969    34.54       28.43                                                   6.10
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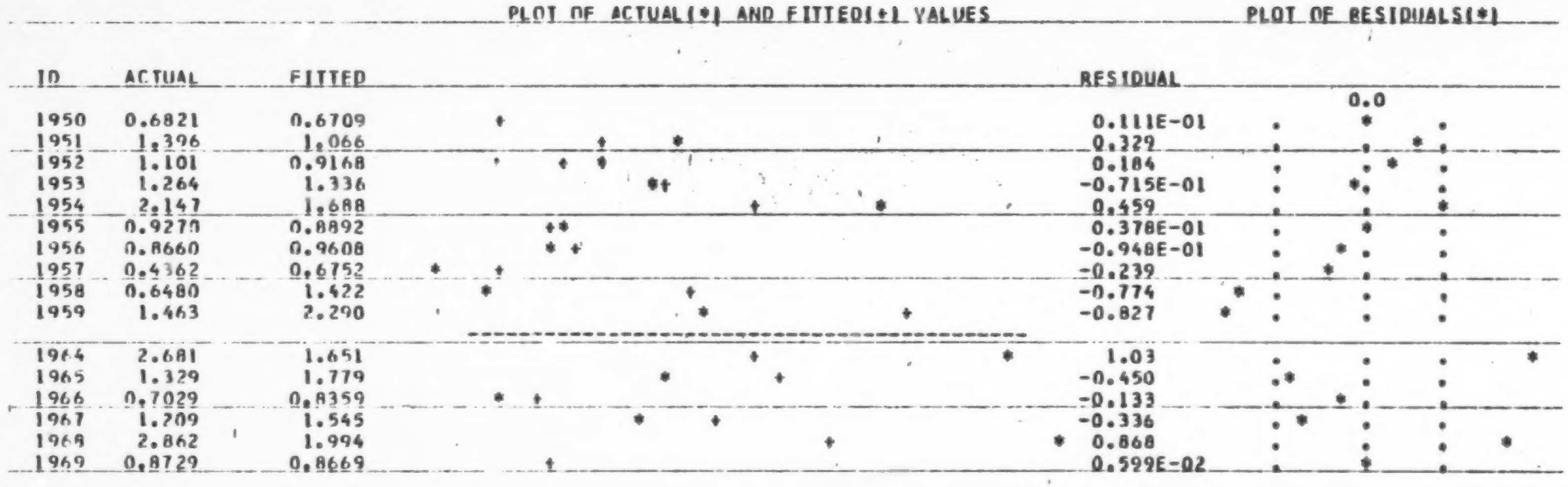
Figure 221. Plots for Nonfatal Injury Rate Per Million Tons, 1950 Through 1959 and 1964 Through 1969: Western Kentucky (CORC)



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                                 PLOT OF ACTUAL(*) AND FITTED(+) VALUES              PLOT OF RESIDUALS(*)

ID      ACTUAL      FITTED                                             RESIDUAL
                                                                                           0.0
1950    0.6821      0.6709                                             0.111E-01
1951    1.396       1.066                                              0.329
1952    1.101       0.9168                                             0.184
1953    1.264       1.336                                              -0.715E-01
1954    2.147       1.688                                              0.459
1955    0.9270      0.8892                                             0.378E-01
1956    0.8660      0.9608                                             -0.948E-01
1957    0.4362      0.6752                                             -0.239
1958    0.6480      1.422                                              -0.774
1959    1.463       2.290                                              -0.827

1964    2.681       1.651                                              1.03
1965    1.329       1.779                                              -0.450
1966    0.7029      0.8359                                             -0.133
1967    1.209       1.545                                              -0.336
1968    2.862       1.994                                              0.868
1969    0.8729      0.8669                                             0.599E-02
```
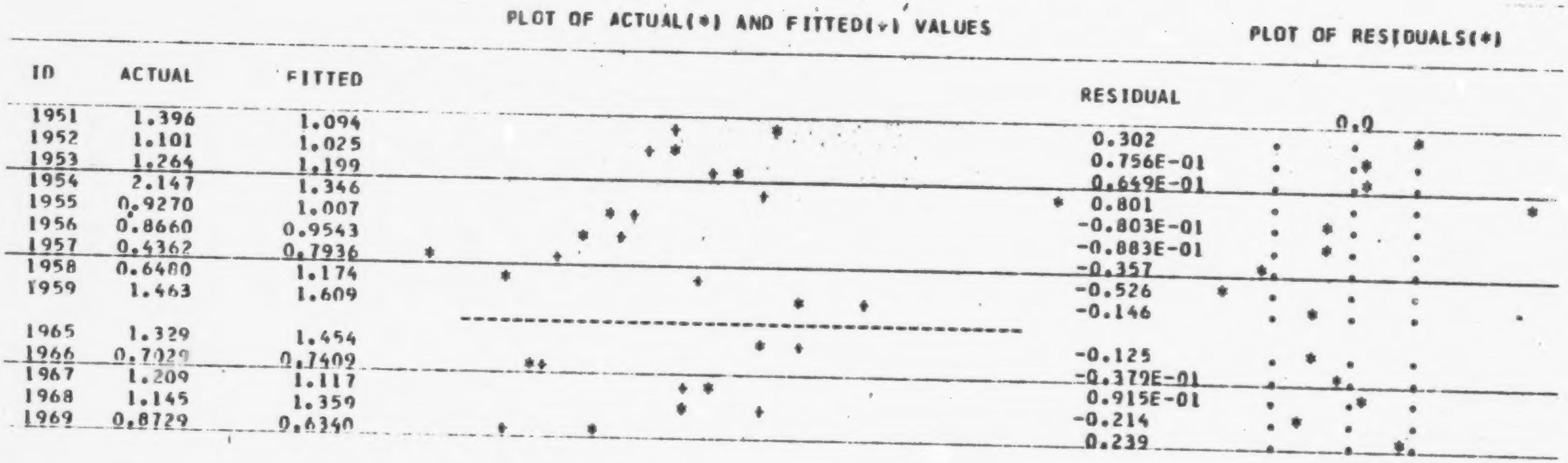

Figure 222. Plots for Fatal Injury Rate Per Million Man-Hours, 1950 Through 1959 and 1964 Through 1969: Western Kentucky (OLS)



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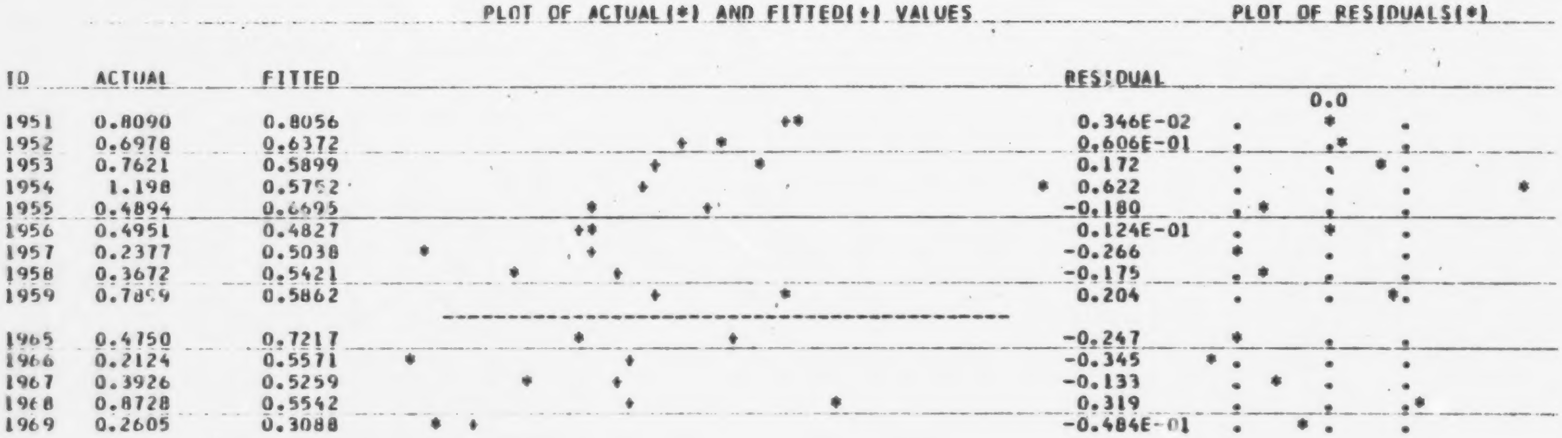
                        PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(*)
ID      ACTUAL      FITTED
                                                                     RESIDUAL
                                                                                        0.0
1951    1.396       1.094
1952    1.101       1.025                                             0.302
1953    1.264       1.199                                             0.756E-01
1954    2.147       1.346                                             0.649E-01
1955    0.9270      1.007                                             0.801
1956    0.8660      0.9543                                           -0.803E-01
1957    0.4362      0.7936                                           -0.883E-01
1958    0.6480      1.174                                            -0.357
1959    1.463       1.609                                            -0.526
                                                                     -0.146
1965    1.329       1.454
1966    0.7029      0.7409                                           -0.125
1967    1.209       1.117                                            -0.379E-01
1968    1.145       1.359                                             0.915E-01
1969    0.8729      0.6340                                           -0.214
                                                                      0.239
```

Figure 223. Plots for Fatal Injury Rate Excluding Disasters Per Million Man-Hours, 1950 Through 1959 and 1964 Through 1969: Western Kentucky (CORC)



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                                      PLOT OF ACTUAL(*) AND FITTED(+) VALUES                      PLOT OF RESIDUALS(*)

ID     ACTUAL       FITTED                                                          RESIDUAL
                                                                                                        0.0
1951   0.8090       0.8056                                    +*                     0.346E-02    .      *     .
1952   0.6978       0.6372                            +  *                           0.606E-01    .     .*     .
1953   0.7621       0.5899                          +       *                        0.172        .      .   * .
1954    1.198       0.5752                         +                              *  0.622        .      .     .         *
1955   0.4894       0.6695                     *        +                           -0.180        . *    .     .
1956   0.4951       0.4827                    +*                                     0.124E-01    .      *     .
1957   0.2377       0.5038       *             +                                    -0.266        *      .     .
1958   0.3672       0.5421              *        +                                  -0.175        . *    .     .
1959   0.7899       0.5862                          +         *                      0.204        .      .    *.
                                   ----------------------------------------------
1965   0.4750       0.7217                    *           +                         -0.247        *      .     .
1966   0.2124       0.5571      *                 +                                 -0.345      * .      .     .
1967   0.3926       0.5259               *       +                                  -0.133        .  *   .     .
1968   0.8728       0.5542                        +               *                  0.319        .      .     .*
1969   0.2605       0.3088        *  +                                              -0.484E-01    .    * .     .
```
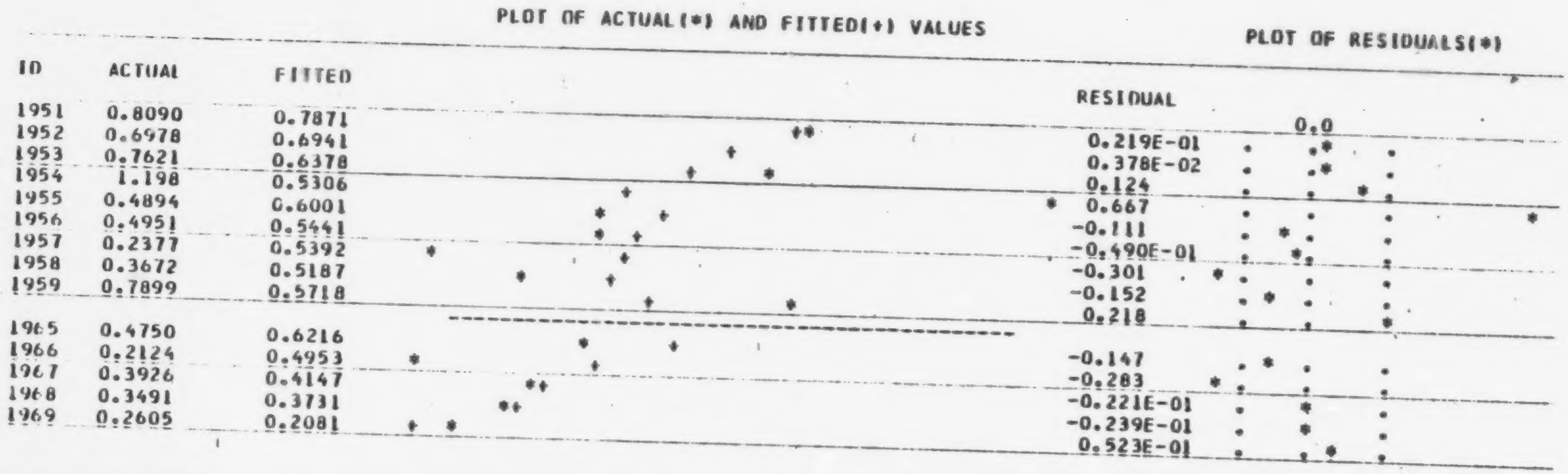

Figure 224 . Plots for Fatal Injury Rate Per Million Tons, 1950 Through 1959 and 1964 Through 1969: Western Kentucky (CORC)



ID	ACTUAL	FITTED	RESIDUAL
1951	0.8090	0.7871	0.219E-01
1952	0.6978	0.6941	0.378E-02
1953	0.7621	0.6378	0.124
1954	1.198	0.5306	0.667
1955	0.4894	0.6001	-0.111
1956	0.4951	0.5441	-0.490E-01
1957	0.2377	0.5392	-0.301
1958	0.3672	0.5187	-0.152
1959	0.7899	0.5718	0.218
1965	0.4750	0.6216	-0.147
1966	0.2124	0.4953	-0.283
1967	0.3926	0.4147	-0.221E-01
1968	0.3491	0.3731	-0.239E-01
1969	0.2605	0.2081	0.523E-01

Figure 225. Plots for Fatal Injury Rate Excluding Disasters Per Million Tons, 1950 Through 1959 and 1964 Through 1969: Western Kentucky (CORC)

Table 156

Comparison of Predicted Levels of Injury Rates Based on Multiple Regressions With Actual Injury Rates: Western Kentucky Underground Rail-Connected Mines

Injury Rate		Year					
		1970	1971	1972	1973	1974	1975
NFRMH (CORC)	Predicted	110.37 (±66.13)	100.19 (±83.57)	94.33 (±88.65)	103.90 (±82.64)	103.30 (±81.35)	101.32 (±107.71)
	Actual	112.89	78.29	80.71	66.00	65.79	68.17
NFRPR (CORC)	Predicted	33.54 (±29.65)	30.66 (±32.90)	29.52 (±43.07)	30.01 (±53.50)	31.68 (±70.51)	35.24 (±102.96)
	Actual	39.25	35.89	41.72	29.35	34.32	50.35
FRMH (OLS)	Predicted	1.18 (±1.40)	2.32 (±1.58)	2.04 (±1.62)	0.98 (±1.56)	1.17 (±1.55)	0.20 (±1.83)
	Actual	1.23	0.66	0.12	0.86	0.0	0.94
FRMHND(CORC)	Predicted	0.87 (±1.00)	1.50 (±1.20)	1.33 (±1.25)	0.70 (±1.18)	0.80 (±1.17)	0.25 (±1.46)
	Actual	1.23	0.66	0.12	0.86	0.0	0.94
FRPR (CORC)	Predicted	0.38 (±0.78)	0.31 (±0.83)	0.13 (±1.00)	0.01 (±1.19)	-0.159 (±1.51)	-0.487 (±2.14)
	Actual	0.43	0.30	0.06	0.38	0.0	0.55
FRPRND(CORC)	Predicted	0.21 (±0.71)	0.15 (±0.77)	0.04 (±0.94)	-0.009 (±1.13)	-0.065 (±1.45)	-0.198 (±2.07)
	Actual	0.43	0.30	0.06	0.38	0.0	0.55

The results of the model using data through 1975 were used to make predictions of injury rates without MACT. These predictions are shown for rail-connected mines in Tables 157 and 158. There are only six cases for which actual injury rates are significantly less than predicted without MACT: NFRMH in 1971 and 1973, FRMH in 1971 and 1972, and FRMHND in 1971 and 1972. In almost all other cases, actual values fall within prediction intervals; approximately 70.0 percent of these are less than the mean. Based only on model predictions, results show that injury rates in 1975 predicted with MACT, as compared to predictions without MACT, show the following percentage decreases: 26.4 for NFRMH, 10.2 for NFRPR, 77.8 for FRMH, 58.2 for FRMHND, 44.2 for FRPR, and 38.3 for FRPRND. This analysis is presented for rail and truck mines in Tables 159 and 160. These results show fourteen cases in which actual rates are significantly less than predicted without MACT; NFRMH in 1970, FRMH in 1970 and 1971, FRMHND in 1970 and 1972 through 1975, FRPR in 1970 and 1971, and FRPRND in 1970 through 1972 and 1974. In all other cases, actual rates fall within prediciton intervals; all but one of these are below the mean of the prediction interval. Based only on model predictions, injury rates in 1975 for all mines show the following precentage decreases: 28.8 for NFRMH, 13.7 for NFRPR, 58.8 for FRMH, 51.0 for FRMHND, 51.4 for FRPR, and 45.2 for FRPRND. Comparison of results for all mines with rail-connected mines suggests the possibility that the negative impact of the Mine Act on injury rates is somewhat underestimated using rail-connected mines only.

Summary

The relationships of the independent variables to the injury rates may be summarized as follows. For nonfatal injury rates: (1) weighted-average seam thickness is negatively related but not significant; (2) percent

Table 157

Effect of MACT on Nonfatal Injury Rates in Underground Rail-Connected Mines: Western Kentucky

Injury Rate	Year	(1) 95.0 Percent Confidence Interval Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean
			Mean			Low	Mean	High -((1) x (2))		Low	Mean	High (3) + (4)		(5) - (4)/(5)
						Nonfatal Injuries Per Million Man-Hours								
NFRMH	1969	-1.565	-0.717	0.131	0				115.9				115.7	
	1970				5.15924	- 0.68	3.70	8.07	107.9	107.22	111.6	115.97	112.9	3.3
	1971				10.4678	- 1.37	7.51	16.38	90.19	88.82	97.7	106.57	78.29	7.7
	1972				29.2330	- 3.83	20.96	45.75	71.14	67.31	92.10	116.89	80.71	22.8
	1973				42.6833	- 5.59	30.60	66.80	76.01	70.42	106.61	142.81	66.00	28.7
	1974				52.0947	- 6.82	37.35	81.53	66.94	60.12	104.29	148.47	65.79	35.8
	1975				39.1479	- 5.13	28.07	66.27	78.17	73.04	106.24	139.44	86.17	26.4
						Nonfatal Injuries Per Million Tons								
NFRPR	1969	-0.735	-0.140	0.455	0				32.71				34.54	
	1970				5.15924	- 2.35	0.72	3.79	36.79	34.44	37.51	40.58	39.25	1.9
	1971				10.4678	- 4.76	1.47	7.69	34.32	29.56	35.79	42.01	35.89	4.1
	1972				29.2330	-13.30	4.09	21.49	33.48	20.18	37.57	54.97	41.72	10.9
	1973				42.6833	-19.42	5.98	31.37	34.40	14.98	40.38	65.77	29.35	14.8
	1974				52.0947	-23.70	7.29	38.29	37.07	13.37	44.36	75.36	34.32	16.4
	1975				39.1479	-17.81	5.48	28.77	48.13	30.32	53.61	76.90	50.35	10.2

Table 158

Effect of MACT on Fatal Injury Rates in Underground Rail-Connected Mines: Western Kentucky

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Fatal Injuries Per Million Man-Hours								
FRMH	1969	-0.043	-0.016	0.011	0				1.19				0.87	
	1970				5.15924	-0.06	0.08	0.22	1.18	1.12	1.26	1.40	1.23	6.3
	1971				10.4678	-0.12	0.17	0.45	1.36	1.24	1.53	1.81	0.66	11.1
	1972				29.2330	-0.32	0.47	1.26	0.89	0.57	1.36	2.15	0.12	34.6
	1973				42.6833	-0.47	0.68	1.84	0.44	<0	1.12	2.28	0.86	60.7
	1974				52.0947	-0.57	0.83	2.24	0.35	<0	1.18	2.59	0	70.3
	1975				39.1479	-0.43	0.63	1.68	0.18	<0	0.81	1.86	0.94	77.8
						Fatal Injuries Excluding Disasters Per Million Man Hours								
FRMHND	1969	-0.033	-0.010	0.013	0				0.98				0.87	
	1970				5.15924	-0.07	0.05	0.17	0.99	0.92	1.04	1.16	1.23	4.8
	1971				10.4678	-0.14	0.10	0.35	1.07	0.93	1.17	1.42	0.66	8.5
	1972				29.2330	-0.38	0.29	0.96	0.74	0.36	1.03	1.70	0.12	28.2
	1973				42.6833	-0.55	0.43	1.41	0.47	<0	0.90	1.88	0.86	47.8
	1974				52.0947	-0.68	0.52	1.72	0.41	<0	0.93	2.13	0	55.9
	1975				39.1479	-0.51	0.39	1.29	0.28	<0	0.67	1.57	0.94	58.2

Table ~~158~~ 160 (Continued)

Injury Rate	Year	95.0 Percent Confidence Interval for Coefficient of MACT			Value of MACT	Reduction in Injury Rate Caused by MACT -((1) x (2))			Prediction of Injury Rate from Model	Prediction of Injury Rate Without MACT (3) + (4)			Actual Injury Rate	Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Fatal Injuries Per Million Tons								
FRPR	1969	-0.035	-0.014	0.007	0				0.42				0.35	
	1970				5.15924	-0.04	0.07	0.18	0.48	0.44	0.55	0.66	0.41	12.7
	1971				10.4678	-0.07	0.15	0.37	0.41	0.34	0.56	0.78	0.29	26.8
	1972				29.2330	-0.20	0.11	1.02	0.23	0.03	0.64	1.25	0.12	64.1
	1973				42.6833	-0.30	0.60	1.49	0.15	<0	0.75	1.64	0.36	80.0
	1974				52.0947	-0.36	0.73	1.82	0.11	<0	0.84	1.93	0	86.9
	1975				39.1479	-0.27	0.55	1.37	0.52	0.25	1.07	1.89	0.57	51.4
						Fatal Injuries Excluding Disasters Per Million Tons								
FRPRND	1969	-0.024	-0.012	-0.00	0				0.32				0.35	
	1970				5.15924	0	0.06	0.12	0.43	0.43	0.49	0.55	0.41	12.2
	1971				10.4678	0	0.13	0.25	0.31	0.31	0.44	0.56	0.29	29.5
	1972				29.2330	0	0.35	0.70	0.24	0.24	0.59	0.94	0.12	59.3
	1973				42.6833	0	0.51	1.02	0.15	0.15	0.66	1.17	0.36	77.3
	1974				52.0947	0	0.63	1.25	0.10	0.10	0.73	1.35	0	86.3
	1975				39.1479	0	0.47	0.94	0.57	0.57	1.04	1.51	0.57	45.2

Table 159

Effect of MACT on Nonfatal Injury Rates in Underground Rail-Connected and Truck Mines: Western Kentucky

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT Mean			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
						Low	Mean	High		Low	Mean	High		
						Nonfatal Injuries Per Million Man-Hours								
NFRMH	1969	-3.368	-0.982	1.404	0				101.5				113.1	
	1970				5.15924	- 7.24	5.07	17.38	118.6	111.36	123.67	135.98	110.6	4.1
	1971				10.4678	-14.70	10.28	35.26	87.24	72.54	97.52	122.50	79.86	10.5
	1972				29.2330	-41.04	28.71	98.46	78.10	37.06	106.81	176.56	84.25	26.9
	1973				42.6833	-59.93	41.92	143.76	74.18	14.25	116.10	217.94	68.54	36.1
	1974				52.0947	-73.14	51.16	175.45	55.74	<0	106.90	231.19	67.60	47.9
	1975				39.1479	-54.96	38.44	131.85	94.87	<0	133.31	226.72	83.66	28.8
						Nonfatal Injuries Per Million Tons								
NFRPR	1969	-1.519	-0.209	1.101	0				32.14				34.39	
	1970				5.15924	- 5.68	1.08	7.84	43.54	37.86	44.62	51.38	39.68	2.4
	1971				10.4678	-11.53	2.19	15.90	32.46	20.93	34.65	48.36	36.77	6.3
	1972				29.2330	-32.19	6.11	44.40	40.65	8.46	46.76	85.05	43.08	13.1
	1973				42.6833	-46.99	8.92	64.84	35.06	<0	43.98	99.90	30.32	20.3
	1974				52.0947	-57.36	10.89	79.13	29.32	<0	40.21	108.45	34.64	27.1
	1975				39.1479	-43.10	8.18	59.47	51.35	8.25	59.53	110.82	46.97	13.7

Table 160

Effect of MACT on Fatal Injury Rates in Underground Rail-Connected and Truck Mines: Western Kentucky

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Fatal Injuries Per Million Man-Hours								
FRMH	1969	-0.075	-0.030	0.015	0				1.50				1.16	
	1970				5.15924	-0.08	0.15	0.39	1.46	1.38	1.61	1.85	1.15	9.3
	1971				10.4678	-0.16	0.31	0.79	0.93	0.77	1.24	1.72	0.62	25.0
	1972				29.2330	-0.44	0.88	6.19	0.24	<0	1.12	2.43	0.23	78.6
	1973				42.6833	-0.64	1.28	3.20	0.56	<0	1.84	3.76	0.81	69.6
	1974				52.0947	-0.78	1.56	3.91	0.25	<0	1.81	4.16	0	86.2
	1975				39.1479	-0.59	1.17	2.94	0.82	0.23	1.99	3.76	1.01	58.8
						Fatal Injuries Excluding Disasters Per Million Man-Hours								
FRMHND	1969	-0.044	-0.027	-0.010	0	0.05	0.14	0.23	1.20				1.16	
	1970				5.15924	0.05	0.14	0.23	1.28	1.33	1.42	1.51	1.15	9.9
	1971				10.4678	0.10	0.28	0.46	0.63	0.53	0.91	1.09	0.62	30.8
	1972				29.2330	0.29	0.79	1.29	0.19	0.48	0.98	1.48	0.23	80.6
	1973				42.6833	0.43	1.15	1.88	0.56	0.99	1.71	2.44	0.81	67.3
	1974				52.0947	0.52	1.41	2.29	0.20	0.72	1.61	2.49	0	87.6
	1975				39.1479	0.39	1.06	1.72	1.02	1.41	2.08	2.74	1.01	51.0

Table ~~160~~ 158 (Continued)

Injury Rate	Year	(1) 95.0 Percent Confidence Interval for Coefficient of MACT			(2) Value of MACT	(3) Reduction in Injury Rate Caused by MACT -((1) x (2))			(4) Prediction of Injury Rate from Model	(5) Prediction of Injury Rate Without MACT (3) + (4)			(6) Actual Injury Rate	(7) Percentage Decreases in Injury Rates Due to MACT Mean (5) - (4)/(5)
			Mean			Low	Mean	High		Low	Mean	High		
						Fatal Injuries Per Million Tons								
FRPR	1969	-0.025	-0.006	0.013	0				0.46				0.26	
	1970				5.15924	-0.07	0.03	0.13	0.46	0.39	0.49	0.59.	0.43	6.1
	1971				10.4678	-0.14	0.06	0.26	0.41	0.27	0.47	0.67	0.30	12.8
	1972				29.2330	-0.38	0.18	0.73	0.27	<0	0.45	1.00	0.06	40.0
	1973				42.6833	-0.55	0.26	1.07	0.21	<0	0.47	1.28	0.38	55.3
	1974				52.0947	-0.68	0.31	1.30	0.19	<0	0.50	1.49	0	62.0
	1975				39.1479	-0.51	0.23	0.98	0.29	<0	0.52	1.27	0.55	44.2
						Fatal Injuries Excluding Disasters Per Million Tons								
FRFRND	1969	-0.023	-0.006	0.011	0				0.37				0.26	
	1970				5.15924	-0.06	0.03	0.12	0.39	0.33	0.42	0.51	0.43	7.1
	1971				10.4678	-0.12	0.06	0.24	0.35	0.23	0.41	0.59	0.30	14.6
	1972				29.2330	-0.32	0.18	0.67	0.23	<0	0.41	0.90	0.06	43.9
	1973				42.6833	-0.47	0.26	0.98	0.19	<0	0.45	1.17	0.38	57.8
	1974				52.0947	-0.57	0.31	1.20	0.20	<0	0.51	1.40	0	60.8
	1975				39.1479	-0.43	0.23	0.90	0.37	<0	0.60	1.27	0.55	38.3

mechanically loaded is negatively related and significant; (3) mine-size variables are positively related and significant; and (4) the Mine-Act variable is negatively related but significant only for NFRMH. For fatal injury rates: (1) weighted average seam thickness is negatively related but significant only for FRMH; (2) percent mechanically loaded is negatively related but significant only for FRPRND; (3) mine-size variables are negatively related for rates per million man-hours and positively related for rates per million tons but not significant; and (4) the Mine-Act variable is negatively related but not significant.

The effects of each independent variable on the injury rates may be summarized as follows: (1) an increase in ST of one inch decreases NFRMH by 3.73, NFRPR by 0.16, FRMH by 0.21, FRMHND by 0.16, FRPR by 0.04, and FRPRND by 0.03; (2) an increase in PMECH of one percent decreases NFRMH by 1.24, NFRPR by 1.02, FRMH by 0.0002, FRMHND by 0.01, FRPR by 0.1, and FRPRND by 0.01; (3) an increase in AP of one million tons increases NFRMH by 63.86 and decreases FRMH and FRMHND by 1.13 and 0.62, respectively; (4) an increase in AEMPL of ten increases NFRPR by 0.24, FRPR by 0.002, and FRPRND by 0.003; and (5) an increase in the value of the Mine-Act variable of one decreases NFRMH by 0.72, NFRPR by 0.14, FRMH by 0.02, and FRMHND, FRPR, and FRPRND by 0.01.

The Mine Act may have had some impact in lessening injury rates in western Kentucky; the strongest evidence is for reduced fatal rates excluding disasters in all mines. However, the statistical support is weak for concluding that the Act reduced the other rates significantly. It is likely that the results for only rail-connected mines underestimate the negative impact of the Act. These conclusions are complicated by the fact that some of the equations were not significant at the 95.0 percent confidence level or greater.

CHAPTER V

SUMMARY AND CONCLUSIONS ON BENEFITS AND COSTS

In this chapter, results of the productivity and injury rate models are summarized, and benefits and costs of the Act are derived in dollar terms and compared.

Results of Productivity Model

The results support the conclusion that the Mine Act has caused declines in productivity in all states analyzed. Piecewise regression reveals that breaks in trend in 1969 from increasing to decreasing productivity are significant at the 99.0 percent confidence level in all states. Model regressions and predictions indicate that at least part of this decline is due to the Mine Act. The coefficient of MACT is negative for all states and significant for all except West Virginia. The following matrix shows which variables are significant and their signs for each "state":

	AP	ST	CM	DO	PR	MACT
West Virginia					-	
Pennsylvania			+	+	-	-
Illinois					-	-
Ohio			+	+		-
Eastern Kentucky						
Rail	+	+	+		-	-
Rail and Truck		+		+		-
Western Kentucky						
Rail	+				-	-
Rail and Truck		-				-

The only unexpected sign is that of ST for western Kentucky rail and truck mines; the expected sign is positive. Although this seam thickness varies by only around two inches, the variable has a downward trend through 1968, than an upward trend. This correlates (negatively) with the trend of productivity, but there is not expected to be any causality associated with this small change in ST. The percentages of variance explained by the regressions range from 89.0 to 97.0. Using results of these regressions with data through 1975, predictions of productivities in 1970 through 1975, no CMHSA, are greater than actual values for all states. Average percentage losses in productivity per year are estimated to be 16.0 in West Virginia, 23.0 in Pennsylvania, 7.0 in Illinois, 34.0 in Ohio, 17.0 in eastern Kentucky and 15.0 in western Kentucky.

Predictions made using results of regressions on data through 1969 are mostly greater than those just summarized. This method of prediction using regressions on data through 1969 produces some results that are judged to be either nonsensical or quite unlikely. First, in West Virginia, predictions of productivity in 1974 and 1975 are negative. This is due to PR having a high, negative coefficient, combined with the large price increases in 1974 and 1975. The negative impact from PR forces predictions to be less than zero. The problem appears to be that prices in 1974 and 1975 (69.4 and 69.8, respectively) are considerably higher than any values of this parameter used to estimate the regression equation, the greatest value having been 42.4. For most states, the regressions using data through 1969, only, produces higher (negative) coefficients for the price variable than those using data through 1975. A second questionable result of this method of prediction is that, in several cases, these predictions are very close to predictions made by extrapolating the trend over time prior to 1970. Predictions based on continuing the same upward trend over time are expected to represent maximum but very unlikely levels of productivity in 1970 through 1975. Numerous observers of the industry have maintained that productivity would not have continued to increase at the same rate in the 1970s as in the past even if the Act had not been passed (Brennan, 1974; Falkie, 1976; Robinson, 1973). Such factors as increased labor unrest and the increase in unauthorized work stoppages, the stagnation of technological improvements, the influx of new, untrained workers, and an increase in the percentage of older mines have all had negative impacts on productivity. Since predictions using this method are derived by extrapolation, while those using results of regressions on data through 1975 are derived by interpolation, the predictions from the latter method are preferred.

Problems with the regression results are a rather high degree of multicollinearity in most cases and positive autocorrelation only for West Virginia and Pennsylvania regressions using data through 1975. With multicollinearity, the least squares estimators of the regression coefficients still have all the desirable properties; however, the variances are large, making the estimates imprecise. Using the principal components method to correct for multicollinearity, the coefficient of MACT remains negative and becomes somewhat larger than in the original regressions. The principal components regressions have consistently lower R^2 values, however. Therefore, the results are not used for calculation of the effect of MACT on productivity. When the disturbances are autoregressive, the least squares estimators of the regression coefficients are unbiased and consistent but not efficient, and calculated confidence intervals are again expected to be wider than the correct ones.

There is no variable in the model for age distribution and experience of miners. Data on age distribution of miners were available in 1976. These are tabulated by state for three age ranges and are shown below.

	<30	30-44	>44
Illinois	33.90	35.74	30.37
Pennsylvania	36.77	26.61	36.62
Ohio	47.49	30.33	22.16
West Virginia	38.84	33.30	27.85
Eastern Kentucky	38.05	37.69	24.27
Western Kentucky	35.65	37.11	27.24

Recall that the average percentage reduction in productivity per year due to MACT for each state is estimated to be, in increasing order: Illinois - 7.0, western Kentucky - 15.0, West Virginia - 16.0, eastern Kentucky - 17.0, Pennsylvania - 23.0, and Ohio - 34.0. The high value for Ohio may be explained, in part, by the large percentage of miners under the age of 30. The low value for Illinois may be explained, in the same manner, by the relatively small percentage of workers in this age range. Age of workers is correlated with experience, so that the ranking of states by age ranges is also a rough ranking by experience levels. The Mine-Act variable may be taking some of the negative impact on productivity of the influx of young, inexperienced workers, thus, resulting in some overestimation of costs of the Act.

There is no variable in the full model for wildcat strike activity or attitudes of workers. Data on wildcat strikes were available only for 1965 through 1974; regressions were made using data for these years only, with a variable for wildcat strike activity. The variable is defined as number of man-days lost in wildcat strikes times 100 divided by total man-days worked (WCT). It proved to be insignificant in explaining productivity, in general, with unexpected positive signs in most cases. In most cases, MACT is significant and has a larger coefficient in the regressions having WCT as a variable than in the regression without this extra variable. The average value of WCT for 1970 through 1975 for each state is shown below.

	Average WCT
Ohio	8.12
West Virginia	6.09
Pennsylvania	4.19
Kentucky	2.18
Illinois	0.08

Separate data on eastern and western Kentucky are not available. Again, recall that Ohio has the largest average percentage decrease in productivity due to MACT and Illinois has the smallest. There is a large difference between their average WCT values, indicating that Ohio had much more wildcat strike activity than Illinois. The relative percentage decreases in productivity may be explained, in part, by this difference in wildcat strikes. While the regression results with WCT seem to indicate the coefficient of MACT without WCT is too small (underestimating costs of the Act), these data ranking states by wildcat strike activity indicate the coefficient of MACT without WCT may be too large (overestimating costs of the Act). Intuitively, the latter effect seems more likely.

Results of Injury Model

Results for the injury model indicate that the Mine Act has caused declines in fatal injury rates, but it has had little consistent effect on nonfatal rates, in general. Piecewise regression indicates that in three states there is a change in trend in 1969 of NFRMH to declining rates, but in one state (Pennsylvania) the change is to increasing rates. NFRPR changes trend in 1969 to increasing rates in three states, while a change to declining rates occurs only in one state (Illinois). Four states have fatal injury rates per million man-hours that change trend in 1969 to lower rates. There are no states that have a significant change in trend in 1969 for fatal injury rates per million tons. The coefficient of MACT is negative and significant for NFRMH and NFRPR in Illinois, Ohio, and western Kentucky; however, it is positive and significant for NFRPR in West Virginia. In cases for which the coefficients are not significant, they have both negative and positive signs. The values of R^2 for NFRMH range from 5.0 to 90.0 percent; for NFRPR, they range from 50 to 95 percent. Using results of these regressions with data through 1975, predictions of nonfatal rates without CMHSA are greater than actual rates in Illinois, Ohio, and western Kentucky; predictions are, in general, less than actual rates in West Virginia, Pennsylvania, and eastern Kentucky. Predictions using regressions on data through 1969 confirm these relationships. Therefore, the Mine Act can be said to have had the expected impact on nonfatal injury rates in only three states; even for these states, in some cases the actual rate falls within the prediction interval. For all fatal injury rates, the coefficient of MACT is negative, as expected. In most cases, the coefficient of MACT is significant for fatal injury rates per million man-hours, and actual rates are less than predicted without CMHSA, although many fall within prediction intervals but less than the mean prediction. Again, predictions based on regressions using data through

1969 confirm these results. For fatal injury rates per million tons, the coefficient of MACT is significant for West Virginia, Pennsylvania, Illinois, and western Kentucky. Predictions without CMHSA are generally greater than actual values, however, many actual values are less than the mean value but within prediction intervals.

Autocorrelation (positive) is a problem only in Illinois for FRMH and FRPR. There are some pairwise correlations that are high, but not as many or as high as for productivity. The use of a principal component results in decreases in R^2 values and significance of MACT similar to that without the principal component; the results are not presented.

Valuation of Benefits

In this section, methods for evaluating the benefits of reducing fatal and nonfatal injuries are discussed, and benefits of the Act are calculated using the results of this study.

Consistency with the accepted criteria of benefit-cost analysis would require that the saving of a person's life be valued at the sum he (and others) would pay for him to remain alive. Under conditions of certainty as to who would be saved from death as the result of a public project, it is expected that, normally, the amount of money would be extremely high, or infinite. Thus, the project should be undertaken no matter what the cost, since benefits would exceed costs. In reality, there is no way to specify precisely what persons will be saved from death or injury if a project is undertaken. The only knowledge that might be available is that a certain percentage of a group will be saved, or that the risk to each person is decreased. The amount now becomes the sum of what each person will pay for this reduced risk for the group. This quantity is no longer likely to be nearly infinite in value. Theoretically, this amount could be determined by each person in a subjective manner based on his perception of the effect on his welfare of a change in risk for the group. The change may be so small as to elicit no change in perceived welfare. However, this value is not easy to obtain as it requires estimates of how many lives will be saved, how many accidents will be prevented, or how many people will experience improved health. Should such values be available, the economist must then obtain subjective valuations through use of surveys based on questionnaires. The difficulty of obtaining meaningful values through the use of surveys is well-known. It is doubtful that many people would know what a change in risk for themselves or others is worth to them. Examples have been cited of receiving different values from the same people for the same risk reduction, depending on how the question is worded. Although this method is theoretically attractive, the practical difficulties, if not impossibilities, of actually obtaining accurate information for the analysis make it necessary to consider alternative methods.

There is considerable literature on the question of how to value life and limb. All of the arguments are not covered here, but some useful references with additional citations are Mishan (1975), Rhoads and Singer (1978), and Jones-Lee (1976) which surveys much of the literature.

The most commonly used method for evaluating the economic worth of a human life is calculating the present value of a person's expected future earnings (Mishan, 1975). This may be expressed as

$$L_1 = \sum_{t=n}^{\infty} E_t P_n^t (1+r)^{-(t-n)}$$

where L_1 = loss to the economy consequent upon the person's death (using gross output approach)

E_t = expected gross earnings of the person during year t, excluding returns on his ownership of non-human capital

P_n^t = probability in year n, the current year, that the person will be alive during the year t, and

r = social rate of discount expected in year t.

The use of this measure is widespread. Most writers point out that, taken to the obvious extreme, there is the dilemma that a retired or other unemployed person has no value to society according to the calculation. Several supplementary calculations have been suggested but not employed. These calculations are meant to take account of the victim's loss of utility from ceasing to live, his suffering, or his family's bereavement.

Another method, related to the first, is calculating the present discounted value of the losses to other people as a result of someone's death. This calculation subtracts the personal expenditures of the individual. This is expressed as

$$L_2 = \sum_{t=n}^{\infty} P_n^t (E_t - C_t)(1+r)^{-(t-n)}$$

where L_2 = loss to the economy consequent upon the person's death (using net output approach)

C_t = personal expenditure by the individual in the year t expected in year n,

and all other terms are defined for the equation for L_1. This method has not been employed, probably because of the assumed policy implications. In this case, some people could have negative worth, retired people for example; the implication is that their death would confer a net benefit on society. On purely economic grounds, the method is unsatisfactory since it disregards the choices of the potential victims.

A third method that has been suggested does not use earnings. The suggestion has been made that an implicit value to human life can be determined by examining the political decisions made on investment expenditures that increase or decrease the number of deaths. However, the political realities involved would make such a measurement questionable. As Mishan (1975) points out, an implicit value attributable to loss of life derived from one public program would quite likely not agree with an implicit value derived from another public program. Furthermore, if a program results in benefits other than saving lives, it would not be valid to assess all the costs of the program towards the saving of lives. It would be difficult, if not impossible, to determine what percentage of the funds were spent for the purpose of saving lives.

A fourth method is based on the notion that the value a man sets on his life can be inferred from the insurance premium he is willing to pay. This principle is of no use in determining how a man values his own life, for the purchase of insurance does not buy a longer life or even a reduced risk of death. The insurance policy provides only for compensation to others in the case of the man's death.

The method used in this study is to value human capital services saved by the Act through calculations of the present value of expected future earnings. A value is also placed on medical costs. First, the actual number of injuries prevented by the Act are estimated as follows. The mean and maximum predicted injury rates without MACT in 1970 through 1975 are transformed into estimated number of injuries per year that would have occurred without the Mine Act. The injury rate is multiplied as appropriate by millions of tons actually produced or millions of man-hours that would have been worked without the Mine Act to produce the same tonnage. This derivation of man-hours is more fully explained in the section on costs. The choice of whether to use NFRPR or NFRMH and of which fatal rate to use to estimate number of injuries of each type is made based on which regression equation is thought to be the best. The major criteria used to choose the best results are significance of the equation as indicated by the F-statistic, absence of autocorrelation, R^2 values, and significance and signs of variables. In several instances, the number of predicted injuries without the Act were less than actual injuries, appearing to indicate that the Act is responsible for causing injuries. Although this is clearly possible since more men were put into the mines, these negative values will be ignored. That is, rather than debiting these from injuries prevented, they will be counted as zero injuries prevented. Actual injuries are subtracted from predicted injuries to determine the estimate of injuries prevented.

The estimated number of fatal and nonfatal injuries prevented are transformed into man-days saved using the following procedure. Nonfatal accidents are divided into three categories of severity of injury based on data in the 1970 through 1975 issues of Injury Experience in Coal Mining. The three categories are (U.S. Department of the Interior, 1975, p. 2):

Permanent total disability - Any disabling work injury other than death that permanently and totally incapacitates an employee from following any gainful occupation, or that results in the loss, or the complete loss of use, of both or any two: hands, arms, legs, feet, or eyes.

Permanent partial disability - Any disabling work injury other than death or permanent total disability that results in the loss, or the complete loss of use, of any member or part of a member of the body, or any permanent impairment of functions of the body or part thereof, regardless of any preexisting disability of the injured member or impaired body function.

Temporary total disability - Any disabling work injury that does not result in death or permanent impairment, but which renders the injured person unable to perform a regularly established job that is open and available to him, during the entire time interval corresponding to the hours of his regular shift on any one or more days (including Sundays, days off, or plant shutdown) subsequent to the date of injury.

This subdivision is done so that different days lost can be attributed for each category. Data are given on number of nonfatal injuries that are permanent total, permanent partial, and temporary total in underground mines for each state. These are applied as percentages to the nonfatal injuries to subdivide them. These reports also provide average severity data (average number of days lost or charged per injury) by state for permanent partial and temporary total injuries for each year. Table 161 presents the mean and maximum number of injuries prevented and average severity by state and year. Number of days charged to a permanent total injury (6,000) is the same as for fatal injuries. These average severity data are used to estimate total days saved for all accidents; that is, average severity for a temporary total accident is multiplied by the number of these accidents to derive man-days. Man-days saved for permanent partial injuries are calculated in the same manner, using

Table 161

Estimated Prevented Injuries‡ and Severities

State	Fatals	Nonfatals Permanent Total	 Permanent Partial	 Temporary Total	 Total	Average Severity (days charged per injury) Permanent Partial	 Temporary Total
Illinois							
1970	6 (7)	0 (0)	1 (1)	34 (56)	35 (57)	635	43
1971	0 (2)	0 (0)	1 (1)	69 (111)	70 (112)	464	13
1972	8 (15)	0 (0)	2 (4)	95 (217)	97 (221)	427	35
1973	18 (31)	1 (1)	3 (6)	304 (488)	308 (495)	185	43
1974	11 (32)	0 (0)	8 (14)	301 (512)	309 (526)	253	60
1975	16 (34)	0 (0)	4 (7)	298 (462)	302 (469)	564	45
Pennsylvania							
1970	0 (1)	0 (0)	2 (3)	47 (97)	49 (100)	414	41
1971	0 (5)	0 (0)	0 (2)	0 (74)	0 (76)	794	12
1972	7 (15)	0 (0)	0 (2)	0 (91)	0 (93)	951	36
1973	12 (24)	0 (1)	2 (8)	83 (430)	85 (439)	575	39
1974	5 (18)	1 (3)	5 (14)	226 (609)	232 (626)	443	54
1975	10 (21)	0 (0)	0 (5)	0 (311)	0 (316)	727	58
West Virginia							
1970	11 (16)	0 (0)	0 (0)	0 (0)	0 (0)	911	38
1971	23 (32)	0 (0)	0 (0)	0 (0)	0 (0)	1280	12
1972	20 (43)	0 (0)	0 (0)	0 (0)	0 (0)	483	28
1973	38 (78)	0 (0)	0 (5)	0 (328)	0 (333)	717	31
1974	20 (55)	0 (1)	0 (7)	0 (563)	0 (571)	318	43
1975	23 (51)	0 (0)	0 (11)	0 (747)	0 (758)	521	45
Ohio							
1970	3 (5)	0 (0)	1 (2)	80 (119)	81 (121)	319	24
1971	2 (5)	0 (0)	0 (0)	0 (0)	0 (0)	274	11
1972	5 (14)	0 (0)	1 (3)	137 (333)	138 (336)	912	21
1973	6 (19)	0 (0)	3 (6)	342 (627)	345 (633)	1163	22
1974	4 (18)	0 (0)	7 (11)	421 (730)	428 (741)	493	41
1975	3 (14)	1 (1)	3 (6)	240 (470)	244 (477)	814	34

Table 161 (Continued)

State	Fatals	Nonfatals				Average Severity (days charged per injury)	
		Permanent Total	Permanent Partial	Temporary Total	Total	Permanent Partial	Temporary Total
Eastern Kentucky							
1970	0 (0)	0 (0)	5 (7)	309 (433)	314 (440)	1043	30
1971	0 (3)	0 (0)	0 (0)	0 (4)	0 (4)	789	11
1972	1 (11)	0 (1)	7 (16)	421(1032)	428(1049)	452	29
1973	6 (21)	1 (2)	7 (24)	365(1327)	373(1353)	605	36
1974	6 (27)	3 (12)	9 (33)	448(1618)	460(1663)	1061	37
1975	4 (21)	1 (4)	3 (19)	195(1079)	199(1102)	428	42
Western Kentucky							
1970	1 (2)	0 (0)	0 (0)	0 (23)	0 (23)	1043	30
1971	1 (3)	0 (0)	0 (2)	0 (151)	0 (153)	789	11
1972	5 (11)	0 (0)	0 (4)	0 (280)	0 (284)	452	29
1973	5 (16)	0 (1)	4 (13)	219 (717)	223 (731)	605	36
1974	14 (38)	2 (6)	4 (18)	204 (872)	210 (896)	1061	37
1975	8 (24)	1 (3)	3 (13)	160 (758)	164 (774)	428	42

‡Numbers are for expected values; maximum predictions for a 95.0 percent confidence interval are given in parentheses.

average severity for this type of accident. Number of fatalities and permanent total injuries are charged 6,000 days per injury, approximately 27 years at an average working year of 222 days. Days saved are then distributed appropriately into the future, assuming a maximum of 222 may be attributed in any year except the twenty-seventh which has 228 days. The starting year is, of course, the year of the predicted injury.

Man-days saved in each year are multiplied by average daily wages. These average daily earnings were obtained for past years from the U.S. Department of Labor Employment and Earnings, U.S. 1909-78 for production workers in bituminous coal and lignite mining. For wages through 2001, the last year benefits would accrue for an injury prevented in 1975, an increase factor in real wages is assumed. This increase is 2.6 percent per year, the average annual increase for the period 1971 through 1977.

Since these benefits occur in the future, as well as in the initial year, 1970, they must be discounted using the present value method. Discounting all benefits and costs that occur in different time periods to the same time period allows comparison of the values. The basis of this method is the recognition that one dollar today is worth more than one dollar in the future, assuming there is no disutility involved. Thus, the real value now of one dollar in the future is somewhat less than one dollar. The equation for calculating present value (PV) is

$$PV = P_t \, (1+r)^{-t}$$

where P_t = monetary value in time t

r = interest rate

t = time period.

For several values in different time periods, the equation is the summation of the values,

$$PV = \Sigma P_t (1+r)^{-t}$$

Much debate occurs over the appropriate interest rate to use. Mikesell (1977) presents a good review of the debate over the social discount rate and the appropriate interest rate for various types of public projects. Most economists think the appropriate rate to use falls in the range of five to ten percent, and these two rates are used in this study.

Present value of future expected income is derived for two cases. The first is derived using the expected value of the number of injuries prevented; the second, seeking to maximize benefits, uses the maximum predicted number of injuries prevented (from a 95.0 percent confidence interval). Present value for both cases, with interest rates of five and ten percent for the expected value and five percent for the "maximum" case, are:

Interest Rate	Present Value of Future Expected Earnings (dollars)	
	Expected Value	Maximum Injuries
0.05	58,130,845	135,672,830
0.10	32,498,205	-----

Another benefit of prevention of injuries is the saving of associated medical costs for treatment and rehabilitation. The only information I could obtain is a figure for combined industry compensation claims and medical costs for 1971 derived for underground coal mines by Stilley (1975, p. 73-75). Although compensation is not a true cost, but is a transfer payment, the portion that is medical costs only cannot be determined. This results in some overestimation of benefits.

Stilley uses the estimation that 1971 premium rates for workmen's compensation and medical expenses for underground mines average $13.36 per $100 payroll. He assumes one-half of this is for disability due to injury; the rest is for disabilities related to pneumoconiosis. Combined with total wages, the cost incurred by the underground sector in medical insurance premiums and compensation is $59,803,000. I further derive an average cost per nonfatal accident of $5895 (in 1970 dollars) by dividing the total cost figure by number of nonfatal injuries in 1971; the cost was deflated to 1970 dollars using the index of medical care prices. However perverse the implications may seem, none of the costs are apportioned to fatal injuries since most fatality victims die in the mine (FMC Corporation, 1976, p. 33), thereby, not incurring medical costs, in general. Nevertheless, since the number of fatal accidents is small relative to nonfatal (1.5 percent of the total), including them would make little difference in the cost per injury figure. This cost per accident is assumed to apply in all years, 1970 through 1975, and all medical costs are assumed to be incurred in the year of the accident.

Again, present value of these benefits is derived for two cases. The first uses the expected value of the number of nonfatal injuries prevented; the second, seeking to maximize benefits, uses the maximum number of nonfatal injuries predicted for a 95.0 percent confidence level. The present value in both cases for interest rates of five and ten percent are:

	Present Value of Medical and Compensation Costs (dollars)	
Interest Rate	Expected Value	Maximum Nonfatals
0.05	25,708,744	79,574,188
0.10	22,259,685	67,996,892

There are other benefits to be derived from reduction in injuries. One is prevention of damage to capital goods as the result of an injury. A second benefit is reduction in the idling of factors of production, both labor and capital, when a mine is closed as the result of an accident. Data are not available on these lost workdays, except for one case of a roof fall resulting in a fatality. This case is reported by FMC Corporation (1976, p. 34) to have resulted in the loss of two workdays. Another benefit is reduction of productivity declines that commonly occur as a result of fatal and certain very severe nonfatal injuries (FMC Corporation, 1976, p. 35). Reduction in cleanup required after accidents would be a benefit of reduced injuries, since labor and capital are used that could be otherwise employed. No data are available on these potential benefits.

There are benefits of reducing injuries and death that relate to the decreased welfare of the victim and those who care for him. Pain and suffering, mental anguish, and bereavement are certainly costs; however, these costs are unquantified and probably unquantifiable.

Valuation of Costs

Costs of the Mine Act are estimated in this section using results of this study on productivity losses and supplementary information available from others on additional cost factors. The cost of productivity losses is the added cost of labor. Other costs due to the Act are operating costs excluding labor and capital costs. There is the additional cost of enforcement of the Act, although theoretically this cost could be very significantly reduced if the requirements were followed voluntarily. However, the Act in Sec. 103 (a) requires "frequent inspections and investigations" (U.S. Federal Coal Mine Health and Safety Act of 1969).

Losses in productivity are used to determine costs as follows. At the higher levels of productivity that would have been experienced without the Act, fewer man-days would have been required to produce the tonnage levels actually achieved. Assuming the same total tonnage would have been produced without the Act, the increase in number of man-days required to produce the actual tonnage for each year is estimated. Predicted levels of productivity (tons per man-day) without the Mine Act, as derived for each state through regression analyses, are divided into the figures for total tonnage for each year to obtain man-days that would have been worked in the absence of CMHSA. These values are subtracted from actual man-days to give the increase caused by the Mine Act.

Dollar values of costs are derived by multiplying by the appropriate daily wages for each year. As explained in the section on benefits, these are real wages in 1970 dollars. However, for this calculation, an increase factor for real wages excluding inflation need not be chosen, since all costs occur in the time period 1970 through 1975 for which real wage rates are known. These computations are performed for two cases. One case uses the expected values of predicted productivities without the Mine Act; the other case uses the minimum predicted productivities (from a 95.0 percent confidence interval) in order to minimize costs of the legislation. The discounted present value of these costs for interest rates of five and ten percent are:

	Present Value of Lower Productivity Costs (dollars)	
Interest Rate	Expected Value	Minimum Productivity Losses
0.05	1,018,093,400	325,340,720
0.10	768,845,940	293,229,090

The Mine Act is responsible for increases in operating costs in addition to labor and capital costs. Little information is available on the approximate magnitude of these costs. Values are obtained from Fettig (1978) on increases per ton attributable to the Act in operating costs excluding labor and capital requirements. The Fettig study derives costs through computer simulation by simulating conditions in the mine both with and without the Act. Production differences in terms of tons per machine shift with and without the Act were calculated and used for cost analysis. It must be noted that the capital costs do not include equipment costs or modifications due to the Act. There are clearly costs for equipment, however; one example is the requirement of canopies on continuous mining machines.

The increases in non-labor operating costs per ton are 1.04 for Pennsylvania, 1.46 for Ohio, 1.27 for eastern Kentucky, and 1.31 for West Virginia (Fettig, p. 45 and 48). Values for Illinois and western

Kentucky had to be estimated, since these "states" were not analyzed by Fettig. They were estimated to increase by 1.40 per ton, the average of the five states analyzed (the four above plus Virginia). Increases in capital costs per ton are 0.89 for Pennsylvania, 0.63 for Ohio, 0.47 for eastern Kentucky, and 0.42 for West Virginia (p. 51). The estimate for Illinois and western Kentucky is 0.64, again, the average of five states analyzed. These values are multiplied by production for each year, and total additional costs due to the Act are obtained. The present value of these costs for interest rates of five and ten percent are:

	Present Value (dollars)	
Interest Rate	Non-labor Operating Costs	Capital Costs
0.05	1,726,427,900	771,743,600
0.10	1,555,768,800	695,487,970

These operating costs excluding labor are greater than the labor costs derived in this study. According to most observers, labor costs are the largest part of operating cost increases. In fact, this relationship holds in the Fettig analysis of cost increases. The problem arises because the increased labor costs of the Act are higher in his study than in this study. Thus, the non-labor operating cost increases are entirely out of line with labor costs derived in this study. The costs derived to compare with benefits do not include these non-labor operating cost estimates, since they are too large in comparison with this study's labor costs.

The number of mine inspectors employed increased by 360 percent from 1969 to 1975; the numbers for this span of years are 305, 564, 1055, 1263, 1226, 1088, and 1404 (U.S. Mine Health and Safety Administration, 1979). Witt et al. (1974) estimated the average annual wage of mine inspectors to be $18,000 in 1972. Assuming that the entire increase in number of inspectors over the 1969 level is due to the Act, the additional number for each year from 1970 to 1975 was 259, 750, 958, 921, 783, and 1099, respectively. The assumption is made that only one-half of these resources in manpower are used for the underground sector. This is thought to be an underestimation, since underground mines are more dangerous and pose more health hazards than surface mines. Thus, it is expected that more inspections are made in underground mines. However, this assumption is adapted in order to be conservative in estimating costs. Multiplying the extra number of men by the wage rate in 1970 dollars for each year, the total present value of costs are approximately:

Interest Rate	Increased Costs for Inspectors (dollars)
0.05	34,070,953
0.10	29,937,733

Comparison of Benefits and Costs and Conclusions

Benefits and costs are summarized and compared in this section, and conclusions are reached. The total present value of benefits quantified, that is, the value of lost workdays prevented and medical costs avoided, are:

	Present Value of Benefits Quantified (dollars)	
Interest Rate	Expected Value	Maximum Injuries Prevented
0.05	83,839,589	215,247,020
0.10	54,757,974	-----

Present value of costs quantified, including increased labor cost, non-labor operating and capital costs, and enforcement costs are:

	Present Value of Costs Quantified (dollars)	
Interest Rate	Expected Value	Minimum-Productivity Losses
0.05	1,823,908,000	1,131,155,300
0.10	1,494,271,600	1,018,654,800

Costs and benefits are compared using the ratio of benefits to costs. If this ratio is greater than one, benefits exceed costs, and a project should be undertaken on the basis of economic efficiency alone. If this ratio is less than one, costs exceed benefits, and the concern must be whether or not unquantified benefits are of sufficient magnitude to make up the difference. Benefit-cost ratios are shown below for expected values of benefits and costs at five and ten percent interest rates and for the case of maximum benefits and minimum costs at a five percent interest rate.

	Benefit-Cost Ratios	
Interest Rate	Expected Values	Minimum Costs and Maximum Benefits
0.05	0.046	0.190
0.10	0.037	---

Results indicate that the ratio of benefits to costs using a ten percent rate of discount and expected values of injuries prevented and productivity losses is only 0.037. Using a rate of discount of five percent allows benefits to increase relatively more than costs since those benefits that extend beyond 1975 are valued at a greater level.

Even at five percent, however, the ratio is only 0.046. Finally, allowing for maximum benefits and minimum costs, the ratio at five percent interest rate is 0.190 less than one to five.

To test the sensitivity of the results to the interest rate, the analysis is conducted for a one percent interest rate, which is much lower than any probable social discount rate or opportunity cost. Under this assumption, benefits are:

	Present Value of Benefits at One Percent Interest Rate (dollars)	
	Expected Value	Maximum Benefits
Future Earnings	96,591,629	239,195,830
Medical Costs	29,079,399	90,939,529
Total	125,671,030	330,135,360

Costs become:

	Present Value of Costs at One Percent Interest Rate (dollars)	
	Expected Value	Minimum Costs
Productivity Loss	1,160,012,400	356,429,830
Capital Cost	845,549,120	845,549,120
Extra Inspectors	76,176,309	76,176,309
Total	2,081,737,800	1,278,155,200

The benefit-cost ratio at a one percent interest rate becomes:

	Benefit-Cost Ratios	
Interest Rate	Expected Values	Minimum Costs and Maximum Benefits
0.01	0.060	0.258

Thus, using an interest rate of one percent with maximum benefits and minimum costs, the benefit-cost ratio is 0.258.

This leads to the conclusion that the unquantified benefits, most especially those to the health of miners, must be of very large magnitude to make up the difference between costs and benefits. At a five percent interest rate, this difference is approximately $1.740 billion; with maximum benefits and minimum costs, the difference is $916 million.

One estimate has been made in an unpublished draft that if all black lung disease were eliminated, this would be a saving of 311 cases per year in all underground mines (nonattributable source). This means 1866 cases would be avoided in six years (1970 through 1975). If this estimate is valid, each case would have to show a benefit of over $930,000. However, this allows none of the excess costs to be attributed to other unquantified benefits, such as pain and suffering. Thus, this figure is thought to have little practical meaning.

A more meaningful estimate is derived using results of a study by Cameron (1976), which estimates the costs of black lung disease-related disability in terms of reduced productivity of the miner disabled by black lung disease. He derives an estimate of cost for all black lung disability of 10.5 cents per ton of coal produced (p. 68). Benefits can be calculated from this figure for the elimination of all black lung disability in 1970 through 1975. Using tonnage figures in the present study, at a five percent discount rate, the present value of benefit is $142.4 million; at a ten percent discount rate the present value of benefit is $128.3 million. Neither of these values makes up the difference between costs and benefits derived in this study.

In summation, the results of this study indicate that fatal injury rates have been decreased by the Mine Act and that nonfatal injury rates have probably been decreased, but to a lesser degree and less consistently from state to state. It is more difficult to draw firm conclusions concerning nonfatal injuries because the data are less reliable. These gains have been achieved at the expense of large losses in productivity.

The study indicates that although productivity losses may not be as great as some other studies have indicated, costs still exceed measured benefits by a large margin. Costs that are not quantified include added operating costs excluding labor and required capital expenditures for new or modified equipment. Unmeasured benefits include health benefits that cannot be fully evaluated at this time, since the effect of health standards on incidence of black lung will not be known until in the future. Other unmeasured and probably unmeasurable benefits include prevention of pain and suffering and bereavement. Values of unmeasured benefits must be large for the CMHSA to represent an efficient use of resources.

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